

# **A Calibration Service for Coaxial Reference Standards for Microwave Power**

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## CONTENTS

1. INTRODUCTION .....	1
1.1 NIST Microwave Power Standards .....	1
1.2 Bolometer Mount-Microcalorimeter Operation .....	2
2. TYPE N AND APC-7 REFERENCE STANDARD DESIGN .....	5
2.1 Mount Body Design .....	5
2.2 Thermistor Bead Assembly .....	6
2.3 Final Design .....	8
2.4 Performance .....	10
2.4.1 Microwave Leakage .....	10
2.4.2 Input Reflection Coefficient .....	11
2.4.3 Dual Element Error .....	11
2.4.4 Mount Settling Time .....	13
2.4.5 Effective Efficiency .....	14
3. MICROCALORIMETER DESIGN .....	15
3.1 Thermopile Assembly .....	16
3.2 Other Design Features .....	16
4. AUTOMATED CALIBRATION SYSTEM .....	18
4.1 SYSTEM HARDWARE .....	18
4.2 SYSTEM SOFTWARE .....	20
4.2.1 Program Features .....	20
4.2.2 Stability Algorithm .....	24
5. CALIBRATION PROCEDURES .....	26
5.1 STEP-BY-STEP DESCRIPTION .....	26
5.2 MEASUREMENT RESULTS .....	27
6. MEASUREMENT CORRECTIONS AND EVALUATION OF UNCERTAINTIES .....	28
6.1 MICROCALORIMETER OPERATION THEORY .....	28
6.2 DETERMINATION OF CORRECTION FACTOR $g$ .....	33
6.3 UNCERTAINTY IN CORRECTION FACTOR $g$ .....	39
6.4 UNCERTAINTY DUE TO VOLTAGE RATIOS .....	42
6.4.1 Power Meter Voltage Ratio .....	42
6.4.2 Thermopile Voltage Ratio .....	43
6.4.3 Thermopile and Nanovoltmeter Nonlinearity .....	44
6.5 MOUNT MICROWAVE POWER LEAKAGE .....	46
6.6 BOLOMETER LEAD RESISTANCE .....	47
6.7 TYPE IV POWER METER ERRORS .....	48
6.8 RANDOM EFFECTS .....	48
6.9 COMBINED STANDARD AND EXPANDED UNCERTAINTY .....	49
7. MEASUREMENT ASSURANCE .....	51
8. FUTURE CHANGES .....	56

9. ACKNOWLEDGEMENTS .....	56
10. REFERENCES .....	57
APPENDIX A. Measured Adapter Loss .....	58
APPENDIX B. Theoretical Adapter Loss .....	60
APPENDIX C. Thermopile Stability Testing .....	63
APPENDIX D. Software Listing .....	69
APPENDIX E. Calibration Report .....	101
APPENDIX F. Instrument Identification .....	109

#### **TRADE NAME DISCLAIMER**

Certain commercial components used in the calibration system are identified in this report in order to adequately document the design. Such use and identification do not imply recommendation or endorsement by NIST, nor do they imply that the identified items are necessarily the best available for the purpose.

# **A CALIBRATION SERVICE FOR COAXIAL REFERENCE STANDARDS FOR MICROWAVE POWER**

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A calibration service at the National Institute of Standards and Technology (NIST) for coaxial microwave power reference standards is described. The service provides measurements of a reference standard's effective efficiency from 50 MHz to 18 GHz at a power of 10 mW. The NIST microwave power standards consist of both a microcalorimeter and an associated reference standard. The reference standard is a bolometric power detector (a thermistor mount). The only thermistor mounts accepted for measurement are those constructed to NIST specifications. These thermistor mounts and the automated microcalorimeter are described. A detailed error analysis with an estimate of the calibration uncertainties and their sources is included. The calibration uncertainty, which is quoted as a function of frequency, ranges from about 0.2 percent at 50 MHz to 0.4 percent at 18 GHz.

Key words: coaxial microwave power standard; microcalorimeter; microwave; microwave microcalorimeter; microwave power measurement; microwave power standard

## **1. INTRODUCTION**

### **1.1 NIST Microwave Power Standards**

The microwave power standards in use at the National Institute of Standards and Technology (NIST) consist of microcalorimeters and associated reference standards [1-4]. Each power standard is made up of both a microcalorimeter and a reference standard. The reference standards are substitution type bolometric power detectors. These detectors are generally called bolometer mounts or simply mounts. In this document the terms "reference standard," "bolometer mount," and "mount" are used interchangeably. Commercial bolometer mounts, especially coaxial units, are generally not suitable for use as a reference standard that is measured by the microcalorimeter. While they have been used by NIST in the past, the resulting calibration uncertainties were higher because of their use.

To meet the need in the microwave community for lower calibration uncertainty, a reference standard designed for use with the microcalorimeter is required. Figure 1.1 shows the coaxial microcalorimeter and the Type N thermistor mount used as the reference standard. This document includes a brief description of the microcalorimeter and the reference standard. Additional design and construction details for both the coaxial microcalorimeters and the bolometer mounts used as the reference standards are available as NIST Technical Notes [5, 6]. These references and those noted previously all include descriptions of the microcalorimeter and bolometer mount operation. However, for convenience a brief summary follows.



Figure 1.1 Coaxial microcalorimeter and coaxial reference standard.

## 1.2 Bolometer Mount-Microcalorimeter Operation

The bolometric power detector uses a heat sensitive resistor (bolometer) which terminates the transmission line and absorbs the microwave energy. Two types of bolometers are used: a platinum wire with a positive temperature coefficient called a barretter, and a thermistor bead with a negative temperature coefficient. The detectors are biased by an external source of dc current (power meter) to an operating resistance that produces a match with the characteristic impedance of the transmission line. Coaxial mounts typically use two bolometer elements which are connected in series for the dc bias, but are in parallel for the rf. Thus, to match the  $50\ \Omega$  characteristic impedance of a coaxial transmission line, the pair is maintained at a series resistance of  $200\ \Omega$ . When microwave energy is applied to the mount, the dc bias supplied by the power meter is automatically reduced to maintain a constant operating resistance [7]. If all the microwave energy incident on the mount were absorbed by the bolometer elements, and if the elements were heated identically by equal amounts of dc and rf power, then the microwave power would be equal to the amount by which the dc power is reduced. This is called a substitution type power meter, because the rf power replaces a portion of the dc bias power. The substituted dc power (also called the bolometric power) is calculated using the equation

$$P_{dc} = \frac{V_1^2 - V_2^2}{R_0}, \quad (1-1)$$

where  $V_1$  is the power meter output voltage (the dc voltage across the bolometer elements) with no rf,  $V_2$  is the power meter output voltage with rf, and  $R_0$  is the dc operating resistance of the bolometer pair (200  $\Omega$  for a coaxial mount).

The microwave energy incident on a mount is not all absorbed by the bolometer elements. The dielectric and conductor losses in the input connector, the input transmission line, and the bolometer mounting structure, plus any leakage from the mount result in a measurement error characterized by a correction factor called the mount efficiency. This efficiency is always less than 1. In addition, the bolometer elements are not heated identically by equal amounts of rf and dc power. This is known as the rf-dc substitution error. The combination of these two effects, which is measured by the microcalorimeter, is a correction factor defined as the effective efficiency  $\eta_e$ . The rf power absorbed at the input of the mount is calculated by dividing the substituted dc power by the effective efficiency. The mount's effective efficiency is independent of mismatch corrections, which are treated separately at the time of calibration transfer to an unknown mount.

The bolometer elements used in the reference standards are thermistors. Thermistors are rugged and resist burnout in the event of an rf overload. They are available commercially as a conveniently usable subassembly. Disadvantages to using thermistors include a continuous drift in the bias current even in a constant temperature environment. Also, thermistors are not usable in an alternative efficiency measurement technique known as the impedance method [8].

The microcalorimeter essentially measures the temperature rise of the bolometer mount connected to it. In the coaxial microcalorimeter, the mount's temperature increase is measured with a thermopile. During the measurement, the microcalorimeter is immersed in a stable temperature-controlled water bath [9, 10] to minimize the effect of external temperature changes. The measurement procedure determines the following at each frequency of interest: the power meter and thermopile output voltages ( $V_1$  and  $e_1$ ) with only dc applied to the mount, and then again ( $V_2$  and  $e_2$ ) with both rf and dc applied. The effective efficiency  $\eta_e$  is calculated at each frequency using the equation

$$\eta_e = g \frac{1 - \left( \frac{V_2}{V_1} \right)^2}{\frac{e_2}{e_1} - \left( \frac{V_2}{V_1} \right)^2}. \quad (1-2)$$

The  $g$  term is a frequency dependent correction factor for the microcalorimeter-bolometer mount combination. It is also known as the calorimetric equivalence correction. The uncertainty of the  $\eta_e$  measurement is determined primarily by the uncertainty in  $g$ . The determination of  $g$  is a major effort that is described in section 6 of this document.

A typical reference standard calibration is done at approximately 125 frequencies from 50 MHz to 18 GHz. Even with the automated system described in section 4, the measurement takes about 40 h. Figure 1.2 shows a typical thermopile output at a few frequencies. The value of  $\eta_e$  for one the reference standards, measured at 125 frequencies, is shown in figure 1.3. The expanded uncertainty in the  $\eta_e$  measurement as a function of frequency is shown in figure 1.4. The basis for determining the uncertainty and the method for combining the different components are also described in section 6.

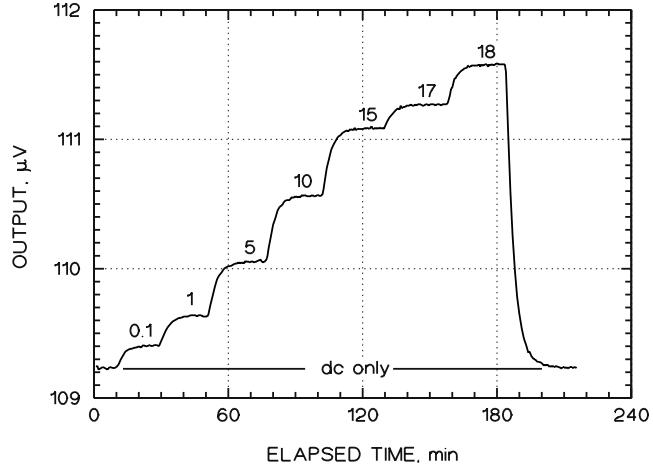


Figure 1.2 Thermopile output versus time for seven frequencies (in GHz).

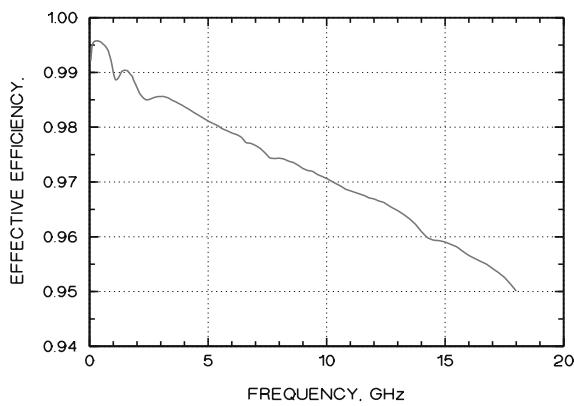


Figure 1.3 Effective efficiency of a Type N mount measured at 125 frequencies.

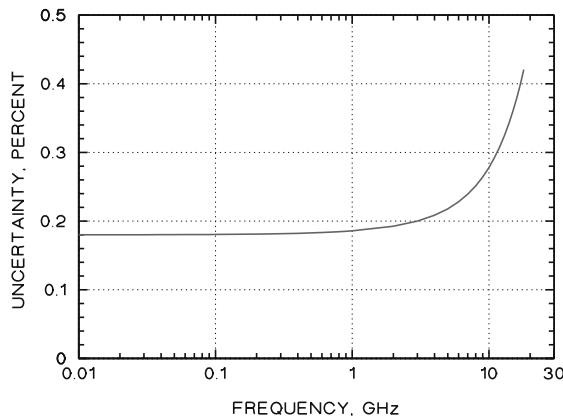


Figure 1.4 Expanded uncertainty for the Type N coaxial microcalorimeter when measuring the effective efficiency of a NIST Type N mount.

## **2. TYPE N AND APC-7 REFERENCE STANDARD DESIGN**

The features of the bolometer mount described below are both desirable and necessary for the mount to be used as an optimum reference standard. The body of the mount and the internal thermistor bead assembly are both considered. Complete design and construction details are available in reference [5].

### **2.1 Mount Body Design**

As noted in the introduction, the primary function of the microcalorimeter is to measure the effect of all microwave energy dissipated in the mount. To best accomplish this, there should be minimal thermal resistance between the heat sources and the measuring thermopile. Thus, the mount should be constructed of a material with a high thermal conductivity, and the thermal paths should be short as possible. Typical commercial mounts are constructed of nickel-plated or gold-plated brass and might also have stainless steel parts in the thermal path.

The transfer standard should have a high effective efficiency. This means a low rf-loss input transmission line made of high electrical conductivity material with low surface roughness ( $\approx 0.5 \mu\text{m}$ ).

To meet these requirements, the mount body is constructed of tellurium copper, while the parts of the mount that involve the input transmission line (the outer conductor) are made of electroformed copper. The electrical conductivity of copper is nearly 3 times higher than brass and 30 times higher than stainless steel. The thermal conductivity is about 2.5 times higher than either brass or beryllium copper and 26 times higher than stainless steel. The electroformed parts provide a better outer conductor surface finish than can be obtained by machining.

The disadvantage of these two materials is that they are softer than beryllium copper or brass. This is more of a liability for the Type N mount (because of the vulnerable outer conductor of the connector) than for the APC-7 design. With careful handling, it is not a major problem with either design. Experience with one of the Type N mounts reveals no visible connector damage after more than 100 connections. All parts of the mount are gold plated to prevent deterioration of the surface characteristics, primarily thermal emissivity and electrical conductivity.

Valid measurements of the thermopile output and the power meter voltage cannot be made until the microcalorimeter and mount are in thermal equilibrium with the water bath, a condition indicated by a stable thermopile output. The time to reach stability may be lengthy: an average of 50 min per measurement frequency (a typical calibration at 108 points can take about 90 h) on the commercial mounts

because of their long thermal time constant. To minimize the effect of external temperature changes, all commercial mounts are typically massive and seek to thermally isolate the thermistor bead structures. Such design objectives are the opposite of those desired for use in the microcalorimeter. An effective way to speed the measurements is to minimize the thermal mass (heat capacity) of the bolometer mount by reducing the size and to eliminate the thermal isolation.

Both techniques are used in the mounts. For example, the mass of the new Type N mount is approximately one-third that of the commercial version previously used (53 g versus 142 g). The average measurement time per frequency for the new design is less than 30 min (see section 4).

The rf leakage from the bolometer mount is a first-order source of error in the measurement. The leakage energy, because it is not dissipated in the mount, is not detected by the bolometer elements or by the microcalorimeter thermopile. Leakage may radiate or conduct through mechanical joints in the mount body, the dc bias leads, or the rf input connector. Commercial mounts, which are adequate for their intended use, generally do not have low enough leakage for this application, where errors on the order of 0.01 percent are of concern.

The effort to minimize leakage has focused on rf containment by the mount body and the dc bias circuit. The shielding is accomplished by totally enclosing the mount and minimizing any gap that might allow leakage at a mechanical joint. Residual leakage from threaded joints can be further reduced by painting the seam with conductive epoxy or paint. Because of the thin wall of the mount body, the cap is not threaded. It is designed to be a tight press fit in the body; in fact, a special fixture is needed to remove the cap. Once it is determined that a newly constructed mount is operating properly, the cap seam can also be sealed with conductive epoxy or paint.

The internal rf bypass structure consists of a tubular pi-section (a pair of capacitors with a ferrite inductor) low-pass filter with an added external ferrite bead in each of four leads. A cross section of the dc feed-through structure is shown later as part of figure 2.1 and 2.2. The dc connection to the thermistor beads is through a miniature connector to allow the mount cap to be removed.

## 2.2 Thermistor Bead Assembly

As described earlier, the substitution type power meter measures power in terms of a change in the dc bias power. Any uncertainty in the bolometer dc resistance will be reflected as an error in the power calculation. Lead or contact resistance in the dc bias circuit will generate such an error. The solution to this problem is a four-wire connection from the bolometer elements to a power meter which uses external

sense leads such as the NIST Type IV power meter (made commercially by several manufacturers). The thermistor bead assembly used in the mount does have the required four-wire connection.

Coaxial bolometer mounts typically use a dual bolometer configuration. The elements are connected in series for the dc bias and in parallel for the rf. This simplifies the dc bias connection and also provides a good rf match to the  $50 \Omega$  transmission line. However, if the electrical characteristics of the two elements are not identical, a dc-rf substitution error in the power measurement results. For thermistor mounts, the error increases nonlinearly with rf power. The error is restricted to coaxial mounts since, in general, waveguide designs use a single element. The effect can be minimized by proper matching of the element pair. The beads in the assembly used are matched to  $0.05 \Omega$  at  $165^\circ\text{C}$ . The details of the dual-element error are presented in reference [11].

Another performance parameter for the mount, which is a function of the bead assembly, is the input reflection coefficient. A low reflection coefficient (less than 0.1) is not necessary for the microcalorimeter measurement, but it is important for reducing the uncertainty in the calibration transfer and for reducing the minimum power requirement on the microwave source.

Another desirable feature of the mount is that the  $\eta_e$  be a smooth function of frequency. Most thermistor mounts display resonances, or sharp narrow dips in  $\eta_e$ . Because  $\eta_e$  is changing very rapidly with frequency at these points, the random uncertainty is greater and interpolation between measured points is not possible. The resonance effect is the result of microwave leakage past the thermistor beads into the space that forms a cavity behind the thermistor bulkhead. The effect can be reduced or eliminated by filling the cavity with two layers of magnetic microwave absorber. The filling material is fastened in place to prevent movement which could change the  $\eta_e$ .

The thermistor bead structure with its unique four-wire connection is a commercial product. This greatly simplifies the construction of the mount. The choice of the particular commercial part does not represent an endorsement of the vendor or the product or imply that it is the best in this application.

### 2.3 Final Design

The final mechanical and electrical design features are indicated in the following two figures. Figure 2.1 is a cross sectional view of the Type N mount with the major parts identified. The same view of the APC-7 mount design is shown in figure 2.2.

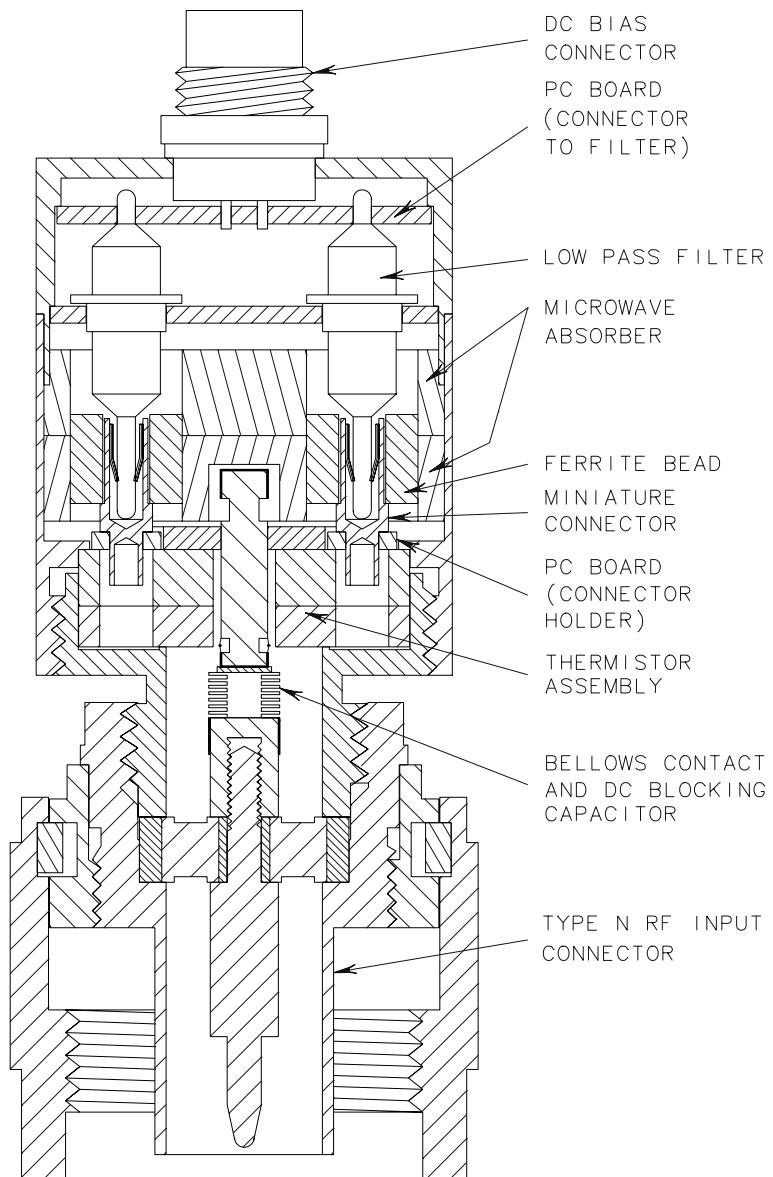


Figure 2.1. Cross section of the Type N thermistor mount.

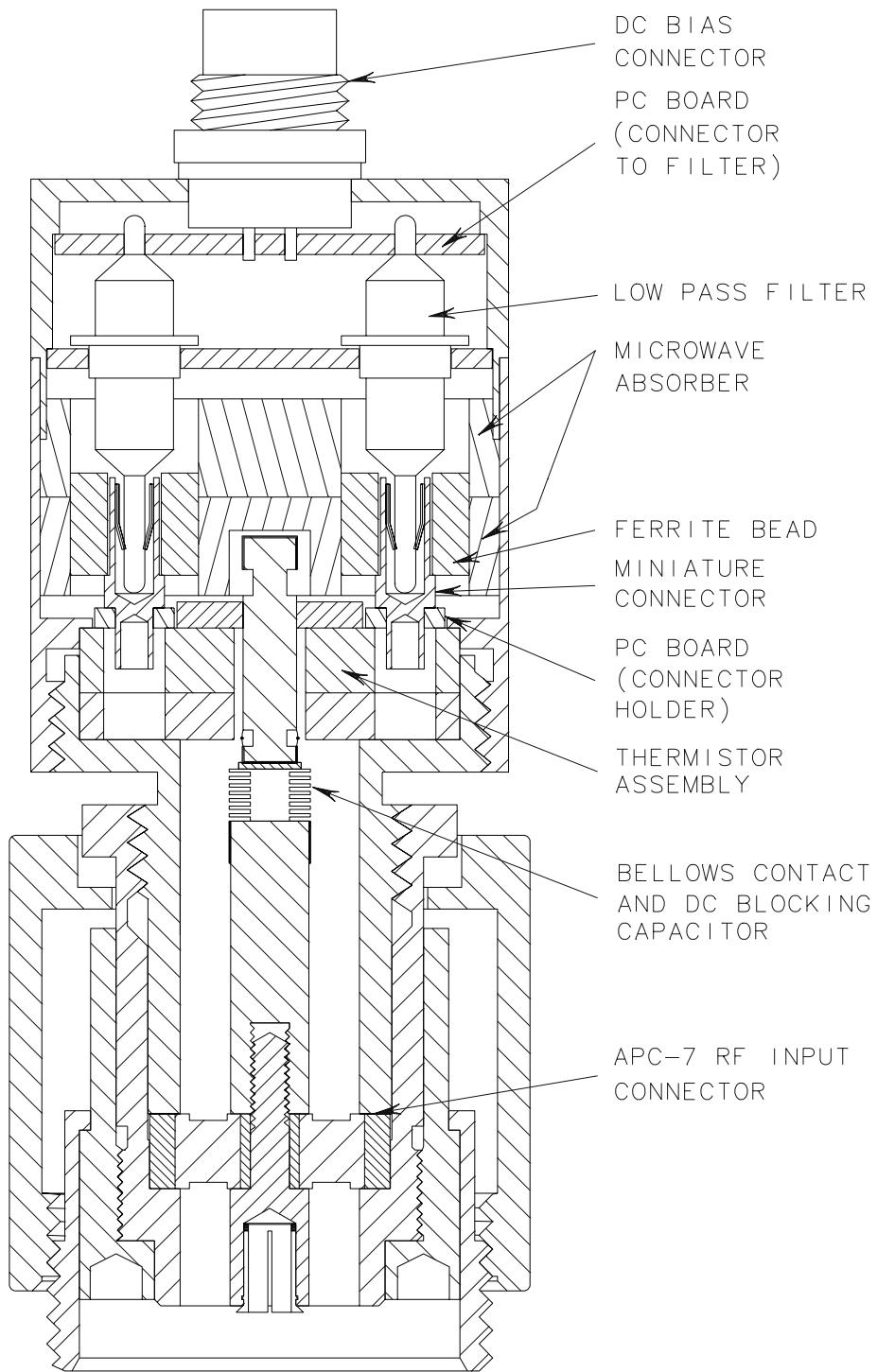


Figure 2.2 Cross section of the APC-7 mount.

## 2.4 Performance

Material presented in this section reports the measured performance of several samples of the Type N mount only. At the time of this publication, customer interest in an APC-7 service has not been sufficient to warrant constructing the mounts or evaluating the calorimeter. The parts, however, are in hand and can be assembled and evaluated if needed in the future. These measurements are thought to be typical and thus representative of future units. The basis of these performance measures was presented earlier in section 2.1.

### 2.4.1 Microwave Leakage

Detection of microwave leakage is relatively easy; accurate measurement of its magnitude is not. Development of special techniques and facilities such as the reverberation chamber and the TEM cell make such measurements potentially possible [12]. A reverberation chamber can be used to measure the energy above about 300 MHz (the low frequency limit is determined by the size of the available chamber) that is radiated from the mount and its connected dc bias cable. Energy that is conducted from the mount on the connecting dc bias cable can be measured using a vector voltmeter and a spectrum analyzer. Measurements on early prototype mounts show that most of the energy escaping from the mount is conducted away on the connecting cable, rather than radiated.

Therefore, measurements were not made in the reverberation chamber.

Results shown in figure 2.3 were obtained from measurements on the mount using a vector voltmeter at the low frequencies and a spectrum analyzer above 1 GHz. The objective is to keep total leakage from the mount more than 40 dB below the input (less than 0.01 percent of the input). The figure indicates that this was achieved.

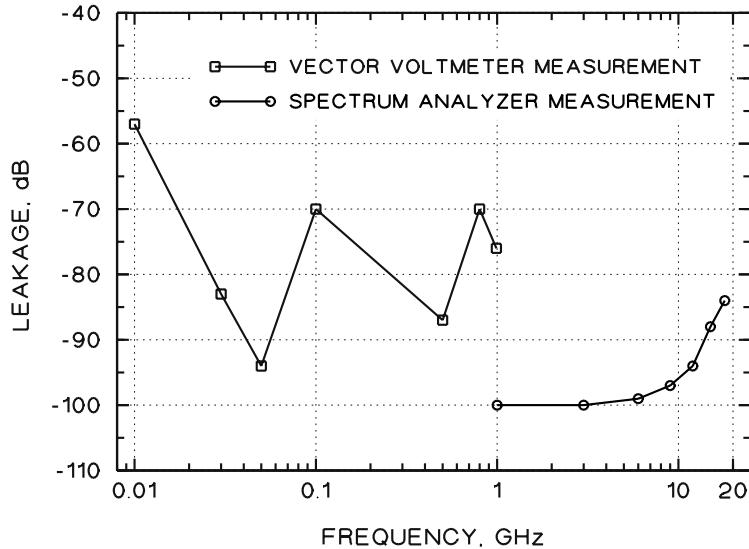


Figure 2.3. Microwave leakage in decibels below the input.

#### 2.4.2 Input Reflection Coefficient

As previously indicated, it is desirable for the magnitude of the input reflection coefficient to be small. The measurements made by an automatic vector network analyzer (45 MHz to 18 GHz) and by a six-port network analyzer (10 MHz to 50 MHz) on a typical Type N mount are shown in figure 2.4. The magnitude is under 0.1 from about 20 MHz to 16.5 GHz.

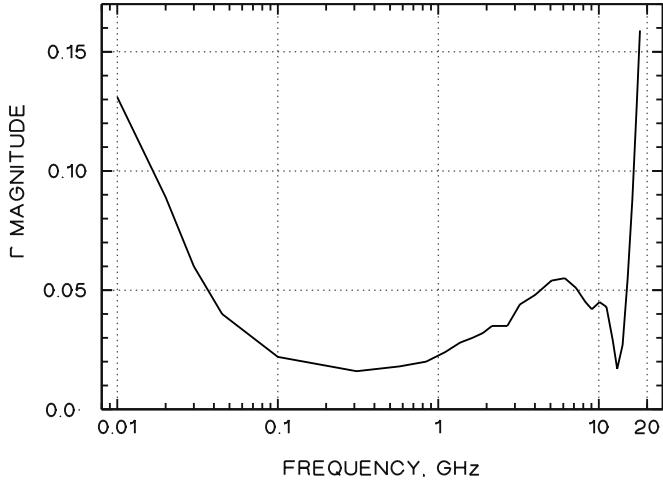


Figure 2.4. Type N mount reflection coefficient.

#### 2.4.3 Dual Element Error

First, we note that if the mount is used at 10 mW, where it was calibrated, there is no error. However, if the mount is used as a reference standard to calibrate another system at a different power, say 1 mW, then there may well be an additional uncertainty in the measurement.

The only way to determine the magnitude of the dual-element error is by direct measurement. In theory, one possible measurement method is to connect the coaxial mount to one arm of a nominally equal power splitter (such as a 3 dB hybrid or a waveguide "magic tee"), and a single-element waveguide mount to the other arm. The ratio of the two bolometric powers is determined at 10 mW and again at a randomly selected power between 10 mW and 0.1 mW. The change in the ratios as determined at the two powers is a measure of the dual-element error. The process is repeated enough times to give a curve showing the nonlinearity as a function of power up to 10 mW.

The test of the procedure is to place identical model waveguide mounts on each arm of the power splitter to verify the linearity of the splitter and associated instrumentation. Figure 2.5 shows results of such a measurement with two identical model waveguide mounts at 9.1 GHz. The increased spread of the data as the power decreases is typical of bolometric measurements because of the small change in dc power that occurs at low microwave power.

The result for a commercial coaxial mount compared with one of the waveguide mounts is shown in figure 2.6. The error is very small at low power and increases to about 0.035 percent at 10 mW.

Unfortunately, most of the data taken using this technique do not give results comparable to figures 2.5 and 2.6. Considerable time has been put into the effort to reduce this approach to a reliable measurement technique. Thus far, it has not been successful. Generally, the results of the power splitter linearity tests have not provided the desired verification, so the comparisons between the coaxial mount and a waveguide mount are not too meaningful. The difficulty seems to be that when looking for deviations on the order of 0.01 percent, instrumentation problems such as the inability to locate the ground precisely where it should be in the dc measurement circuit are of the same order. At best, the comparison between the coaxial and waveguide mounts is in error by the amount of the apparent nonlinearity seen when comparing a waveguide mount to a waveguide mount.

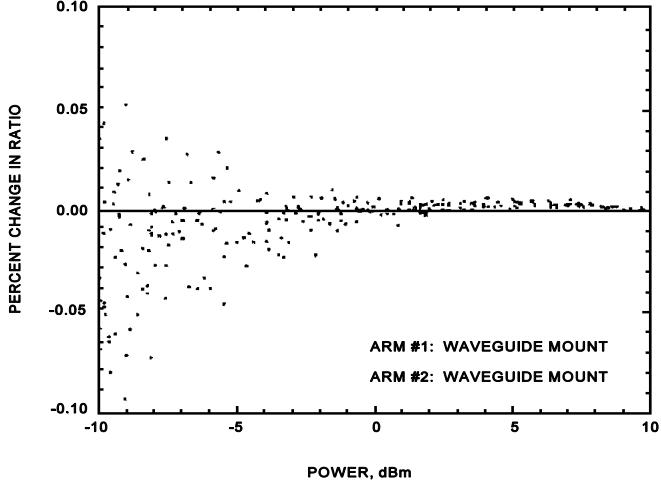


Figure 2.5. Change in the power ratio of two waveguide mounts versus power.

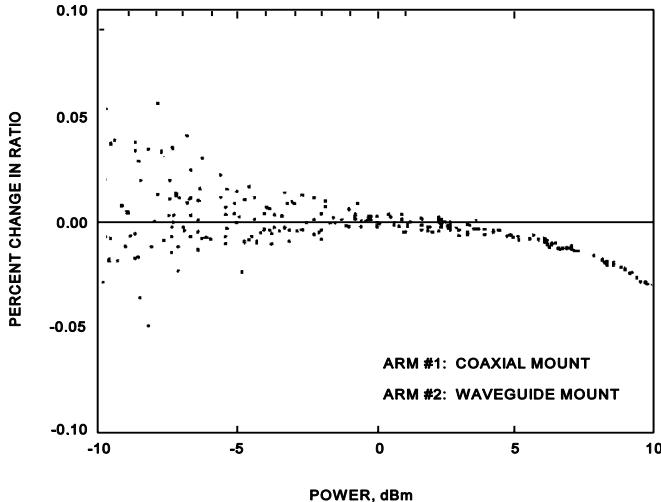


Figure 2.6. Change in the power ratio of a coaxial mount to a waveguide mount versus power.

Another way to determine the dual-element error is to measure the effective efficiency as a function of power. Figure 2.7 shows that measurement on a Type N mount. The significant nonlinearity above about 12 mW is largely due to the dual-element error. At the lower powers the measurement uncertainty becomes large, so the shape of the curve is not necessarily accurate. A line fitted to the measured data between 5 mW and 12 mW is shown in figure 2.8. Based on this linear fit, the change in efficiency for this mount between 10 mW and 1 mW is less than 0.01 percent. This is a better estimate of the dual-element error than the power splitter method provides.

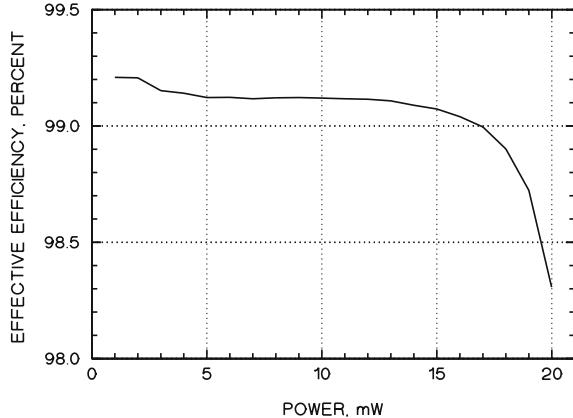


Figure 2.7. Effective efficiency as a function of power.

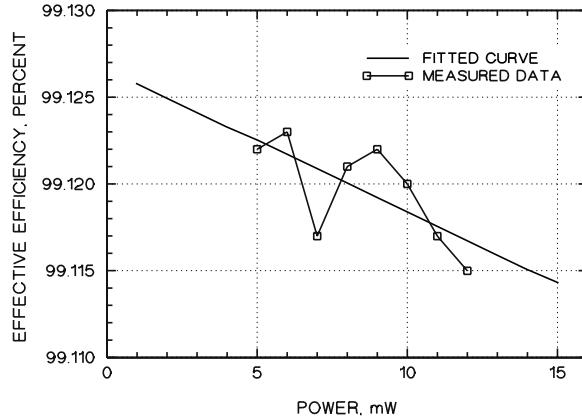


Figure 2.8. Linear fit to data of figure 2.7 from 5 to 12 mW.

#### 2.4.4 Mount Settling Time

In figure 2.9, the upper trace is the output of a crystal detector monitoring a 10 GHz source as the rf is turned on for about 6 ms and then turned off. The lower trace is the power meter voltage of the coaxial thermistor mount as it measures the same output. Note the large "overshoot" excursions that occur for about 2 ms until a steady state is reached. These excursions may occur because the current distribution in the thermistor beads changes when rf is applied, so the heat distribution must also change. It takes a few milliseconds for a new thermal steady state to be reached.

Thus the measurement of the power meter voltages should not be made until after the overshoot has subsided. The effect decreases with power and is independent of frequency.

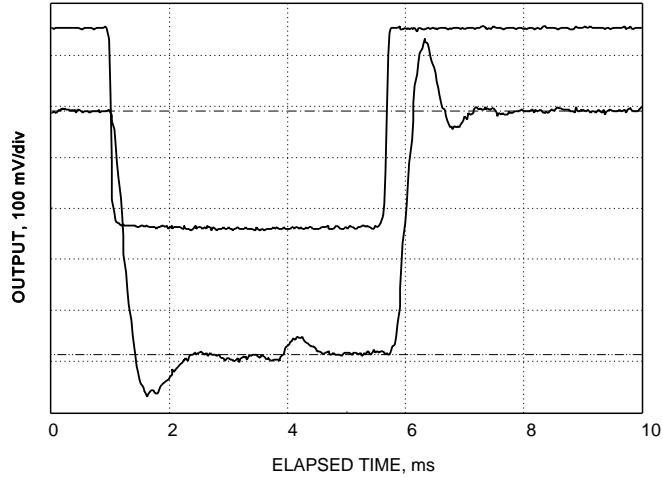


Figure 2.9. Crystal detector and mount output as rf power is switched on and off. The source output is 10 mW.

#### 2.4.5 Effective Efficiency

A plot of the effective efficiency of one of the Type N mounts is shown in figure 1.3. The efficiency is well above 90 percent and decreases smoothly with frequency. Figure 2.10 is a plot of the effective efficiency of a mount before and after suppression of the resonant behavior with microwave absorber as described earlier.

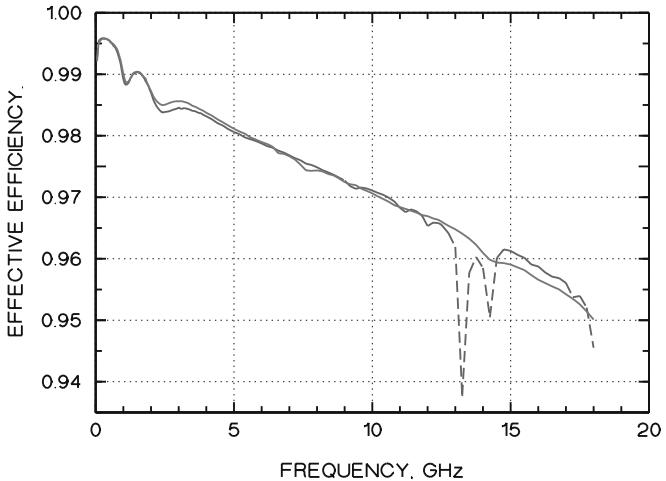


Figure 2.10. Effective efficiency of a Type N mount before (dashed line) and after resonance suppression.

### 3. MICROCALORIMETER DESIGN

As noted in section 1, the primary function of the microcalorimeter is to measure the effect of all microwave energy dissipated in the reference standard bolometer mount. This is accomplished by using a thermopile to measure the temperature rise of an attached bolometer mount with respect to a thermal reference ring under two conditions. The first condition is with dc only dissipated in the bolometer mount and the second condition is with both dc and rf dissipated in the mount. Because the temperature changes are very small (on the order of 0.05 °C), the microcalorimeter is also designed to be immersed in a stable temperature-controlled water bath [9, 10] during the measurement to minimize the effect of external temperature changes. The water bath is controlled to about  $\pm 20 \mu\text{C}$  at near room temperature. Figure 3.1 is a cross sectional view of the base of the microcalorimeter with the major parts labeled. Complete design and construction details are available as reference [6].

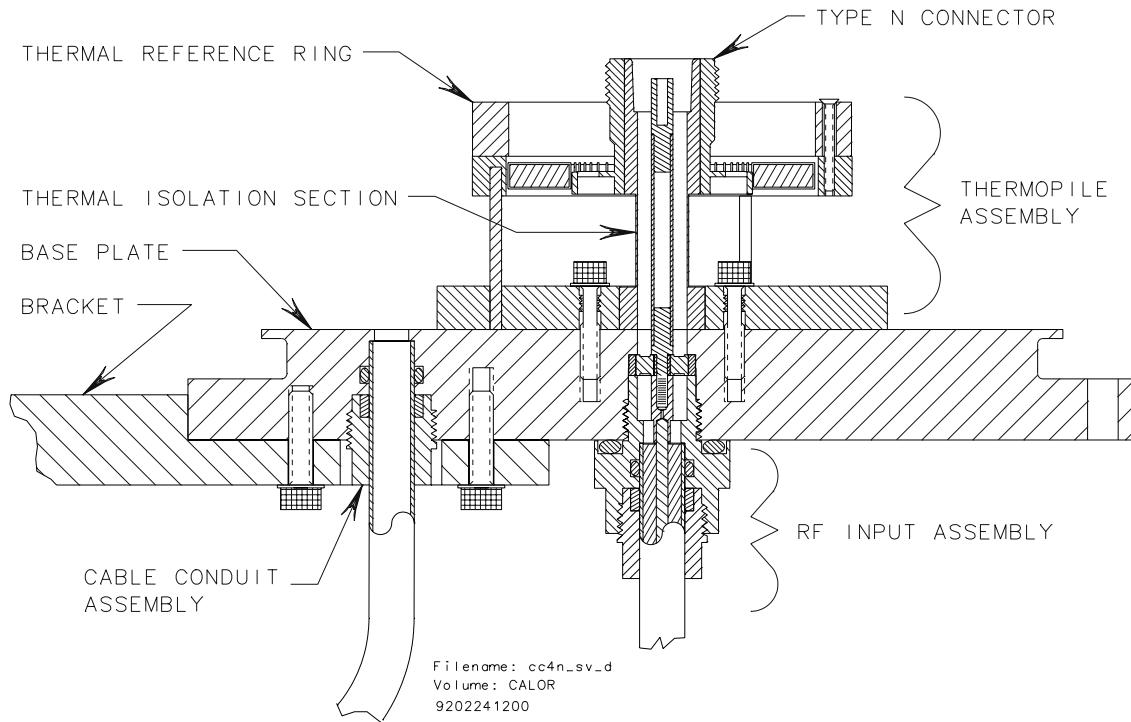


Figure 3.1. Cross section of the Type N microcalorimeter.

### **3.1 Thermopile Assembly**

This part contains a thermal isolation section as well as the thermopile itself. The thermal isolation section, which is between the baseplate (in close contact with the water bath) and the bolometer mount, allows the mount temperature to rise with respect to the baseplate. The isolation section is a short length of coaxial transmission line made with a thin-wall copper outer conductor and a hollow thin-wall gold-plated stainless steel inner conductor.

The thermopile is a ring made of 66 equally spaced radial turns of Constantan wire; the lower half of the ring is copper plated giving 66 copper/Constantan junctions around both inner and outer circumferences. The ring of inner thermocouple junctions is in thermal contact with (but electrically insulated from) the 7 mm coaxial outer conductor just below the coaxial connector. The circle of outer thermocouple junctions is in contact with a thermal reference ring which approximates the thermal characteristics of the dummy reference standard used in the earlier twin-joule microcalorimeter design as described in references [1] and [2].

The thermocouples in the thermopile are connected in series, so the thermopile output can be increased by increasing the number of junctions. The number of thermocouples in the original thermopile was limited by the input range, 100  $\mu$ V, of the potentiometer used to measure the thermopile output. Since the microcalorimeter described here uses the original thermopile assembly, it has less thermocouple junctions than it would otherwise. A thermopile with many more junctions and made of finer wire would be a better match to the 2 mV range of the modern electronic nanovoltmeter now used. A typical thermopile output at a few frequencies for one of the reference standards is shown in figure 1.2.

### **3.2 Other Design Features**

The rf input leads, the mount's dc bias leads, and the thermopile's output leads are brought in through the bottom of the microcalorimeter. This provides a more convenient arrangement for removing the top cover and also keeps the leads in the water bath for a greater distance to provide better thermal tempering.

The entire assembly, including the cover, is gold plated for corrosion protection. The gold-plated interior of the cover is polished to provide a high infrared reflectivity. Figure 3.2 is a partial cross sectional view of the entire calorimeter with the cover raised. When in use the unit is suspended in the temperature-controlled water bath by the rod extending from the top of the cover. The actual water level when in the bath is indicated.

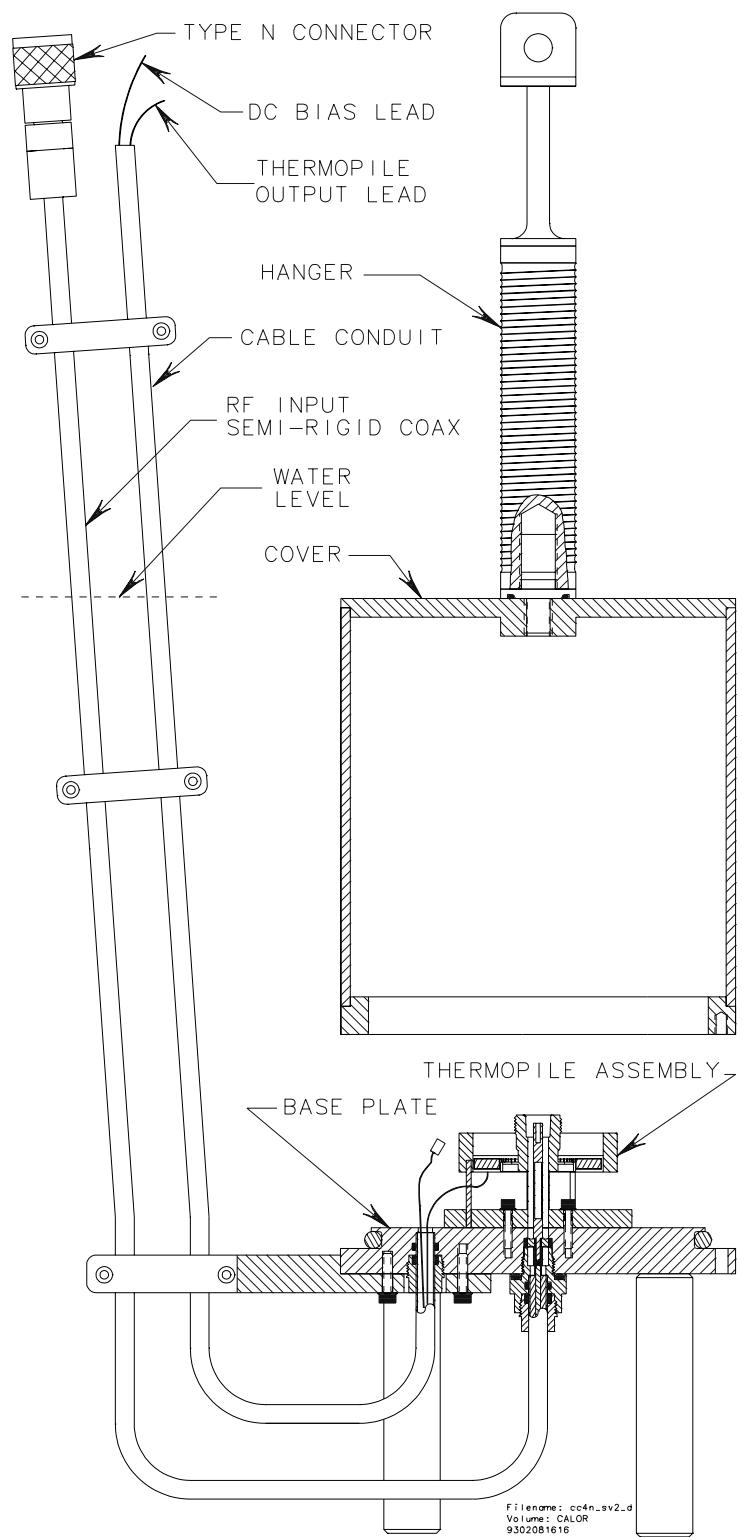


Figure 3.2. View of the entire microcalorimeter assembly.

## 4. AUTOMATED CALIBRATION SYSTEM

The automated system provides a completely unattended measurement of the effective efficiency once the reference standard and microcalorimeter are connected and placed in the temperature controlled water bath. The automation is accomplished using off-the-shelf computer controlled GPIB instrumentation and custom software.

### 4.1 SYSTEM HARDWARE

The measurement console containing two automated systems, one in each rack, is shown in figure 4.1. Except for items 7 and 9 each system has an identical set of instruments. The right-hand rack is intended

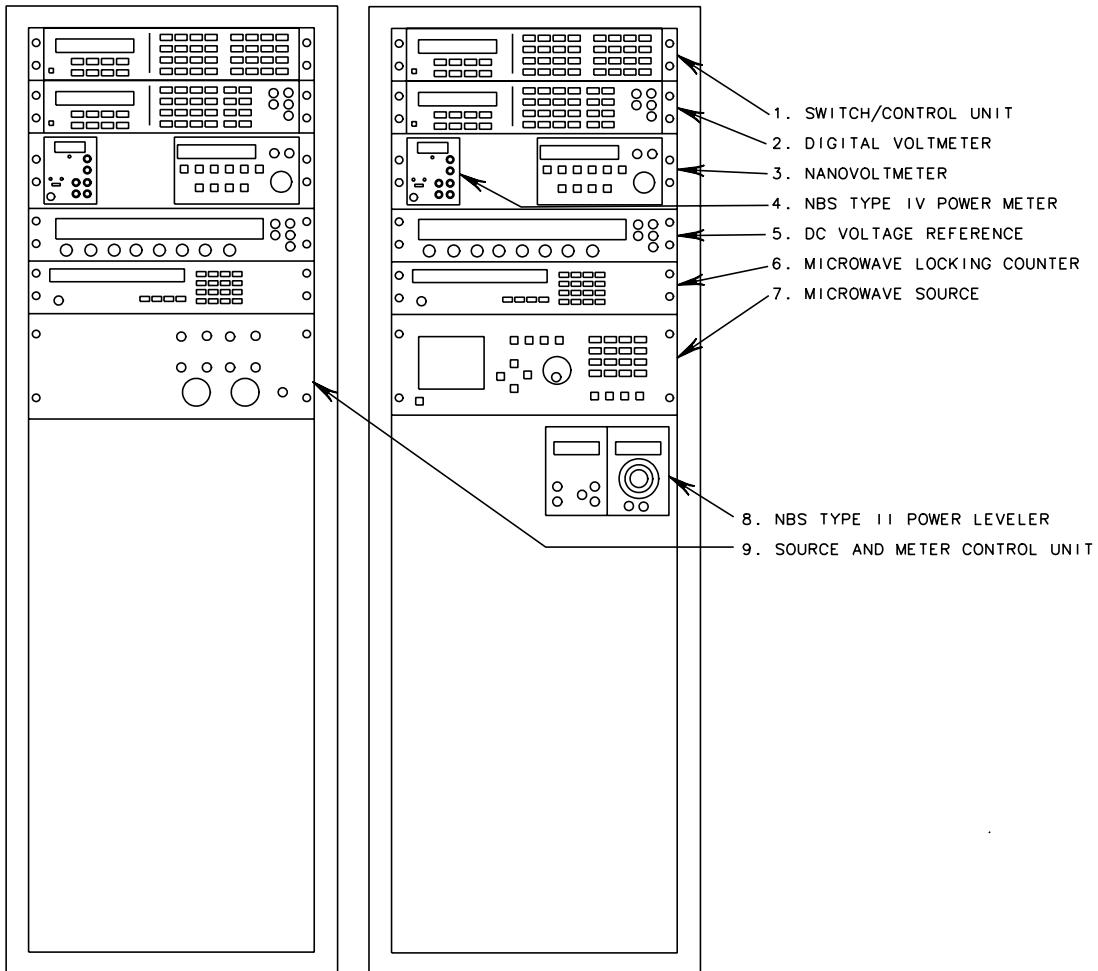


Figure 4.1. Automated calibration system instrument rack.

primarily for coaxial calibrations because the microwave source, item 6, has a 10 MHz to 20 GHz frequency range. The system in the left-hand rack is used with the waveguide microcalorimeters.

Item 1, the switch control unit, provides bus control for the different connections required as the measurement is made. Item 2, the digital voltmeter, measures the output from item 4, the Type IV power meter. Item 3 is a nanovoltmeter used to measure the thermopile output. A precision dc source, item 5, is used as the reference voltage for instrument 8, the NBS Type II power leveler. Item 6 is a locking counter which phase locks the microwave source, unit 7. Item 9 is a custom control unit for the individual YIG tuned FET oscillators used as sources for the waveguide microcalorimeters. Not shown in figure 4.1 are the two instrument controllers. The actual instruments used are identified by item in Appendix F.

A schematic diagram of the instrument connections is shown in figure 4.2.

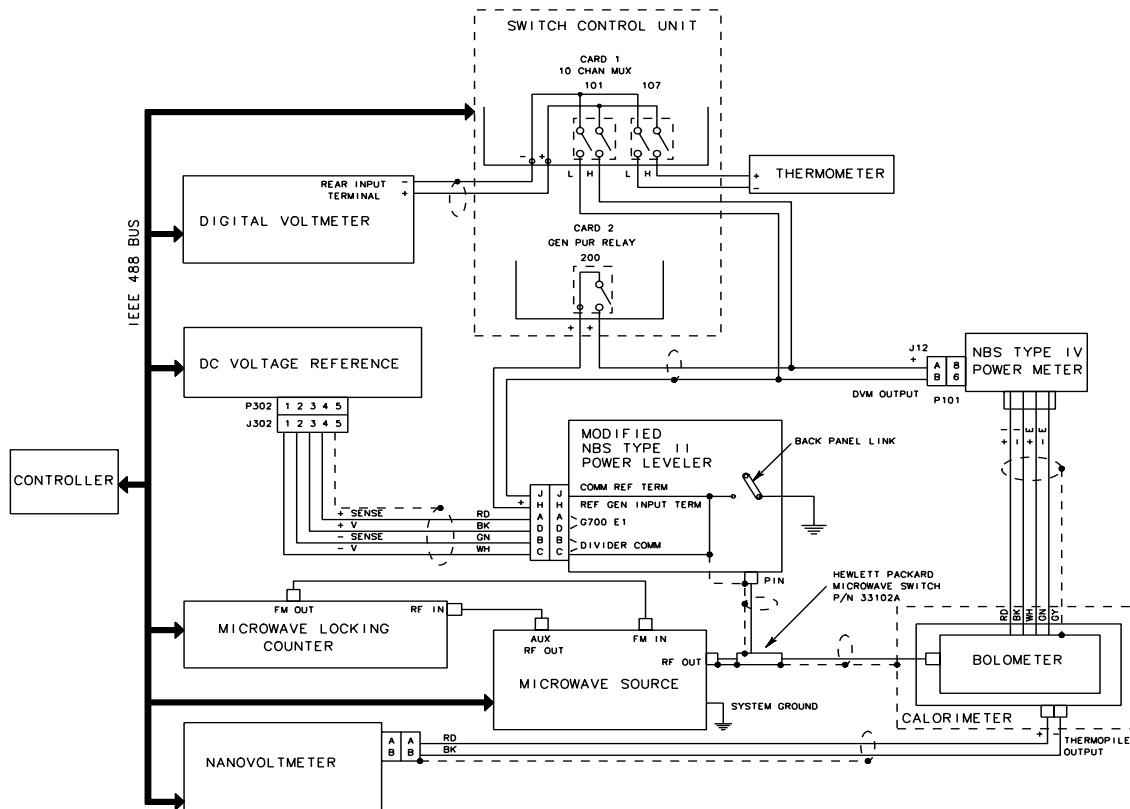


Figure 4.2. Automated calibration system schematic diagram.

## 4.2 SYSTEM SOFTWARE

The measurement program, called MICRO\_CxAP, is written in HP BASIC (also known as Rocky Mountain BASIC or RMB). The program controls the measurement and does the post-measurement processing needed to compute the effective efficiency. A post-measurement computation is required because of the need to correct for the effect of drift in the reference standard bias voltage during the measurement.

### 4.2.1 Program Features

The program is menu driven, with soft keys used for much of the input. The first menu encountered in running the program is shown in figure 4.3. The reverse video items at the bottom of the screen are soft key definitions. When item 1 is selected, a series of screens is presented that set the initial conditions by asking for the measurement frequencies, the serial number of the reference standard, the scale factors for the real time graph, the desired time delay before starting the measurement, and whether a nanovoltmeter zero offset measurement will be included. One of the initial screens sets up the program to measure at five test frequencies when a mount is first connected to the microcalorimeter. After these results are entered into the program, the mount is removed, reconnected, and measured again at the five test frequencies. If the two sets of measurements agree within established limits, the program automatically continues the measurements over the full set of desired frequencies.

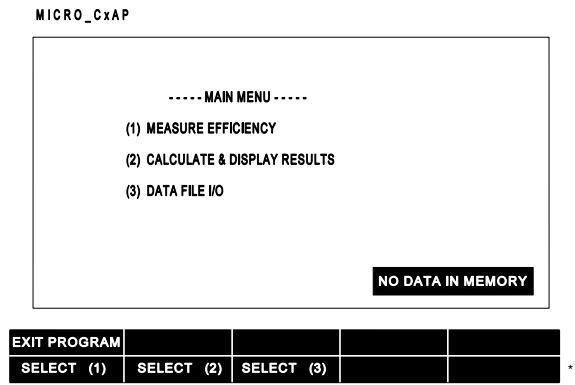


Figure 4.3. First program menu.

During the measurement a real-time graph is displayed on the monitor that shows the thermopile output and other information. Figure 4.4 is an example of the real-time display as the program is measuring the five test frequencies. Information about the program appears in the three windows at the top. The center and right windows can each be toggled to display additional information in another window. The information found in the left-hand window labeled "HEADER INFO" is self explanatory. The center window labeled "LAST READING" gives the total time since the measurement started, the elapsed time since switching to the frequency presently being measured, the total count of data points measured since the start, a countdown that gives the time remaining until the next reading and directions for switching to the alternate window. The right-hand window labeled "THERMOPILE OUTPUT & TEMP" shows the

most recent nanovoltmeter reading of the thermopile output, the average of the last 18 thermopile voltage readings, two spaces for possible future readings of the room and water bath temperatures, and directions for switching to the alternate window. Figure 4.5 shows the real-time display with the alternate center and right windows. The center window labeled "SYSTEM PARAMETERS" shows the present measurement frequency, the last voltage reading from the power meter, the setting of the reference voltage for the power leveler, a calculated value for the substituted dc power in the reference standard, a countdown that gives the time remaining until the next reading, and directions for switching back to the original window. The alternate right window labeled "STATISTICS" shows variables related to the stability algorithm which is explained in section 4.2.2 and Appendix C.

During the measurement the data are taken as the frequency is incremented (tests have shown no difference in results if the frequency is stepped incrementally, or if it is changed randomly) from 50 MHz to 18 GHz. The frequency range is broken into four segments: 50 MHz to 2 GHz in steps of 50 MHz, 2.1 to 4 GHz in steps of 100 MHz, 4.2 to 12.4 GHz in steps of 200 MHz, and 12.5 to 18 GHz in steps of 250 MHz. All of the measured data for each frequency segment are automatically saved to disk individually, with a name that includes the date and time at the beginning of the measurement. An example of the file name is shown under "HEADER INFO" in figure 4.4. The "cn" indicates the reference standard is a Model CN coax mount and "92031711" indicates the measurement was started between 1100 and 1200 h on Mar. 17, 1992. The program completes all four segments automatically without operator intervention.

After completing the entire measurement sequence, the program will return to the main menu. The data from the last set of measured frequencies will still be in memory. Item 2, "CALCULATE & DISPLAY

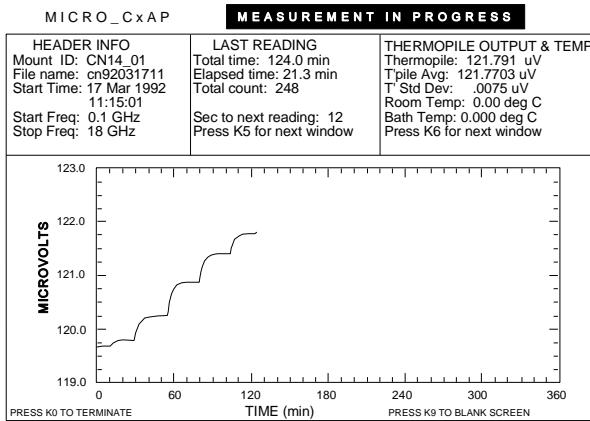


Figure 4.4. Real-time display.

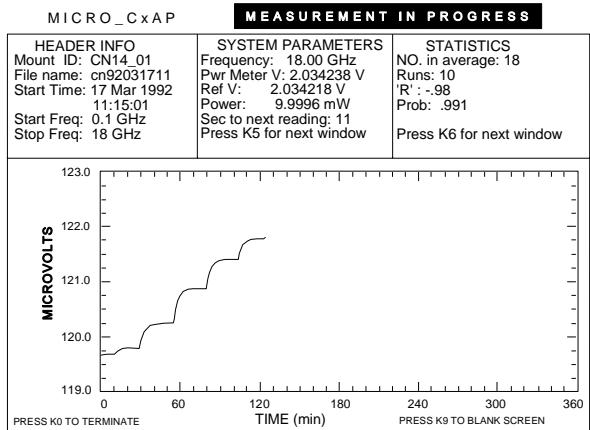


Figure 4.5. Alternate real-time display.

"RESULTS", is selected. This produces the menu shown in figure 4.6 with options to plot the power meter voltage, plot the thermopile voltage, calculate the efficiency, plot the rf power, plot the temperature (if it had been measured), and calculate the standard deviation of any selected set of data points. The plots are useful to get a quick overview of the measurement results to see that the data looks reasonable before calculating the efficiency.

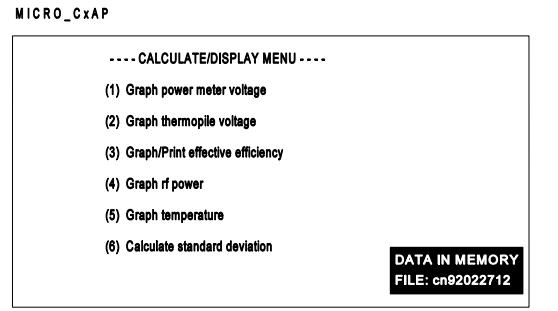


Figure 4.6. Calculation and display menu.

When the program calculates the effective efficiency, four plots at each frequency are optionally available. Examples of these plots for a measurement made at 15 GHz are shown in figures 4.7, 4.8, 4.9, and 4.10.

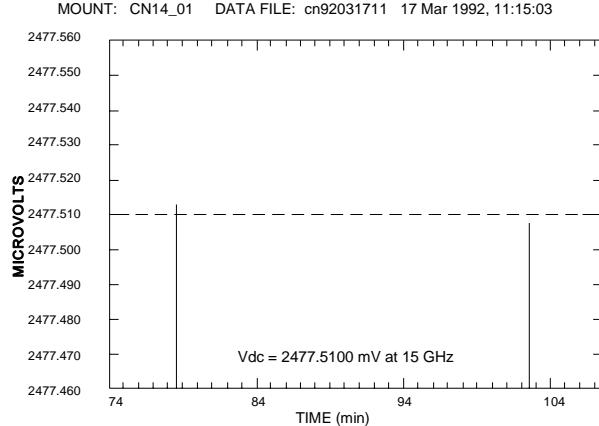


Figure 4.7. Power meter voltage with rf off.

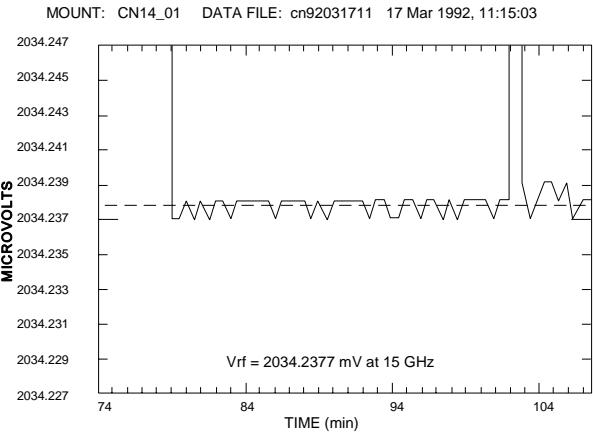


Figure 4.8. Power meter voltage with rf on.

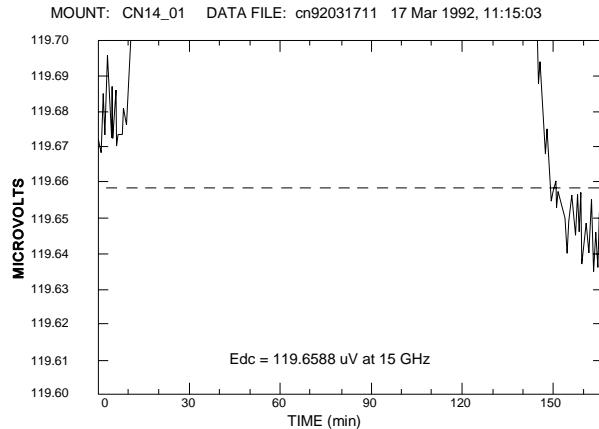


Figure 4.9. Thermopile output with rf off.

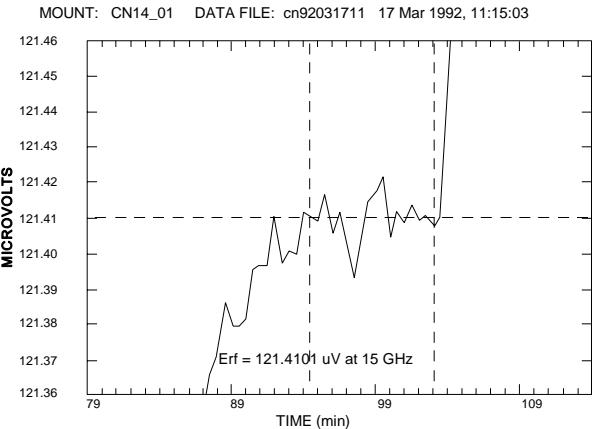


Figure 4.10. Thermopile output with rf on.

The horizontal dashed line in each plot shows the value calculated by the program for each variable. The exact numerical value is displayed at the bottom of the plot. Refer to section 6.1 for a description of the variables and equation used to calculate the effective efficiency. There is a change of variable between these figures and eq (6.1.20): Vdc, Vrf, Edc, and Erf in the figures equal  $V_1$ ,  $V_2$ ,  $e_1$ , and  $e_2$ , respectively, in the equation.

In figure 4.7, note that the rf is off only for the initial and final readings and the calculated Vdc is the average of the two readings. In figure 4.8, the calculated Vrf is the average of all the readings taken while the rf is on. Note that the power leveler keeps the power meter voltage constant within a single count of the DVM. In figure 4.9, the calculated Edc is taken from a linear fit between the average of the initial readings (taken while the rf is off) and the average of the final readings (again while the rf is off) at the time corresponding to the center of the stabilized thermopile output when the rf is on (about 99 min from figure 4.10). In figure 4.10, the value of Erf is the average of the 18 readings between the 2 vertical dashed lines. The decision that stability had been reached in the thermopile output was made by the stability algorithm described in section 4.2.2. The program determines these variables and then calculates and plots the effective efficiency for each frequency measured.

Figure 4.11 is an example how the screen looks when the effective efficiency is plotted. The X and Y axis can be changed to scale the graph and the numerical values can be listed to the screen or printed.

Figure 4.12 shows the screen listing (only a portion of the listing is shown, the rest can be scrolled). The effective efficiency values are now part of the original data file, and the file is saved to disk as described in the next paragraph.

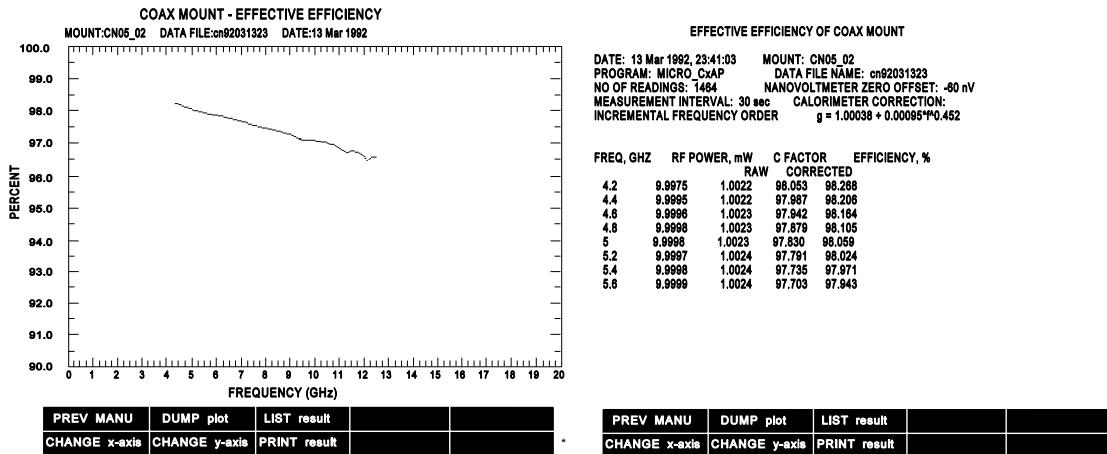


Figure 4.11. Effective efficiency plot.

Figure 4.12. Screen listing.

MICRO\_CxAP

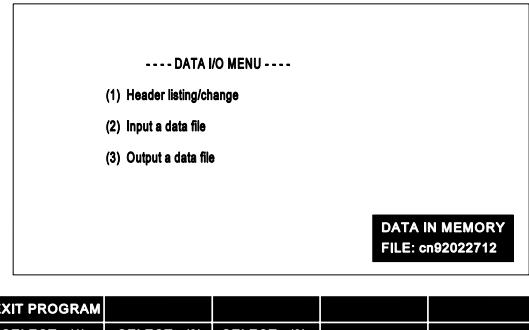


Figure 4.13. Data I/O menu.

To save the data file (or input the data file for the next frequency segment), return to the main menu (figure 4.3), and select option 3, "DATA FILE I/O". This produces the screen shown in figure 4.13. The first item is an option to list the header that is part of each data file. The header, which contains information about the measurement, is shown as it lists to the screen in figure 4.14 (all of the header is shown in the figure, but the actual screen has to be scrolled). As indicated by the soft key options, it may be changed if needed. The item to input a data file also has the option to catalogue any mass storage unit on the system to obtain or check the file name if needed. Once the name is typed in, soft key options input the file from any mass storage unit connected to the controller. The data file output choice includes the option to change the file name, as well as save to any mass storage unit.

Once the efficiencies for all the measured frequencies have been calculated and saved, another program is used to collect them into a single file (which does not contain any of the raw data). This file is used to generate the final calibration report.

#### 4.2.2 Stability Algorithm

One of the critical points in the measurement is the determination of when the thermopile output has reached equilibrium or stability. This is especially difficult because the bias voltage for the reference standard essentially never stops changing; in other words, an aging process is always going on. This means there is always a drift in the thermopile output, aside from the effect of the microwave loss. In addition, the nanovoltmeter reading is fairly noisy because the measurement is being made at about 100  $\mu$ V, which is just 5 percent of the lowest range (2 mV) on the instrument. An algorithm to determine when stability has been reached under these conditions has been developed by the NIST Statistical Engineering

HEADER LISTING FOR: A Previous Measurement

Option Array #  
(1) ----- Data file name: cn920231323  
(2) ----- Mount ID: CN05\_02  
(3) ----- Measurement program: MICRO\_CxAP  
(4) [1] Revision #: 9202031349  
(5) [2] Test date: 13 Mar 1992, 23:41:03  
(6) [3] Band ID: Coax  
(7) [4] Effective efficiency flag: 1  
(8) [5] No. of measurement frequencies: 42  
(9) [6] Start frequency: 4.2 GHz  
(10) [7] Stop frequency: 12.4 GHz  
(11) [8] Step frequency: .2 GHz  
(12) [9] Number of measurements: 1464  
(13) [10] Measurement duration: 12.20 hr  
(14) [11] Measurement interval: 30 sec  
(15) [12] Nominal power: 10.0 mW  
(16) [13] Voltage reference: 0 volts  
(17) [14] Mount operating resistance: 200 ohms  
(18) [15] Nanovoltmeter zero correction: -6.E-8  
(19) [16] Mount pre\_bias flag: 0  
(20) [17] Room temperature: 0  
(21) [18] Bath temperature: 0  
(22) [19] Zero correction flag: 0  
(23) [20] Auto meas flag: 1  
(24) [21] Random freq order flag: 0

EXIT PROGRAM			CONTINUE				*
SELECT (1)	SELECT (2)	SELECT (3)					

Figure 4.14. Header listing.

Division. The algorithm is described in detail in Appendix C. Refer back to figure 4.10 as an example of the thermopile output when it was determined that stability had been achieved. The dashed line is taken to be the thermopile output and is the average of 18 successive measurements between the 2 vertical lines. The right vertical line is the point at which the algorithm decided the output was stable.

## 5. CALIBRATION PROCEDURES

This section describes the process followed in performing the effective efficiency measurement. Since the measurement is automated, the manual part of connecting the standard, setting up the software, and producing the measurement report are the primary things described. The description is appropriate for a new operator's training and thus detailed.

### 5.1 STEP-BY-STEP DESCRIPTION

The following steps are carried out in performing the calibration of a reference standard.

1. The Type N connector on the reference standard is inspected closely (under a microscope) for dirt and physical damage. The connector is cleaned if necessary. This is a precaution taken to avoid damaging the microcalorimeter connector, since the effective efficiency measurement is not affected to first order by the mount's reflection coefficient. The critical Type N connector dimension is measured (and compared with previous measurements if this is not the first calibration). This ensures that there will not be a destructive interference when the standard is mated to the microcalorimeter.
2. Any moisture retention by the reference standard or in the microcalorimeter has proven to give erroneous, nonrepeatable results in the efficiency measurement. Be sure your hands are clean and dry before handling the standard and that no water drops are in the microcalorimeter when the cover is replaced. An effective means of being certain that excess moisture is not present in the reference standard is to place the standard in a vacuum for a few hours.
3. The reference standard is connected to a power meter and biased with dc for a period of two to three days. This reduces the bias drift that occurs when the unit is placed in the microcalorimeter.
4. The reference standard is connected to the microcalorimeter using a Type N torque wrench (approximately  $1.13 \text{ N} \cdot \text{m}$  ( $10 \text{ lbf} \cdot \text{in}$ )). The cover is placed on the microcalorimeter, the total unit is placed in the water bath, the Type IV power meter and nanovoltmeter leads are connected, the dc bias is turned on, and the entire unit is allowed to temperature stabilize for at least 1 h. If at that point the power meter and thermopile outputs are fairly stable (an operator's judgement call learned by experience—actually the program will not start the measurement if the drift rate is too high) the first of the measurements can be started. Section 6.4.1 describes a first-order drift correction made when the effective efficiency is calculated.

5. The program called "MICRO\_CxAP" is loaded and set up to run the five check frequencies. Information about the program and how to use it can be found in section 4.2. When the program is run, a 3.5 in diskette with sufficient space must be in drive 0 (the left side) of the dual 3.5 in drive. The effective efficiency is measured at five check frequencies, 0.1, 3, 5, 10, 15, and 18 GHz. This takes four to five hours, and the data are saved to disk. The program is run again to compute the results.
6. The microcalorimeter is then disconnected from the power meter and nanovoltmeter, removed from the water bath, the cover removed, and the standard disconnected. The calorimeter is left open for at least 15 to 30 min and then the mount is replaced for a second connect, and the process described by step 5 is repeated, except the results from step 5 are entered into the program before it is run again.
7. If the second five-frequency check result repeats within  $\pm 0.06$  percent, the program automatically runs the full frequency set. (The measurement is made without disconnecting the mount.) Again, a 3.5 in diskette with sufficient space must be in drive 0 (the left side) of the dual 3.5 in drive. The effective efficiency is measured at 124 frequencies, 0.05 to 18 GHz. This takes about 40 h, with the data saved to disk in four files. As described in section 4.2, the program is run again to compute and save the results.
8. A program called "MICRO\_DMA" is used to extract the effective efficiency from the four data files saved in the last step. The program combines the four segments and saves the results as a single ASCII file which is converted to a DOS file and used to produce the final test report.
9. As described in step 6, the microcalorimeter is removed from the water bath, and the mount removed. This completes the measurement.

## 5.2 MEASUREMENT RESULTS

The results in the Report of Calibration are listed in a table that gives the effective efficiency, Type B uncertainty, and expanded uncertainty for each frequency. An example of the report can be found in Appendix E.

## 6. MEASUREMENT CORRECTIONS AND EVALUATION OF UNCERTAINTIES

The factors listed below all contribute to the measurement uncertainty and are included or mentioned in the analysis. A correction is determined for the combined effect. The standard uncertainty for the correction factor and for the remaining uncertainty components is determined by either a Type A or a Type B evaluation [13] as appropriate.

1. Nonlinearity of thermopile and nanovoltmeter.
2. Instrumentation errors (voltmeters and dc-substitution power meter).
3. External temperature stability.
4. Microcalorimeter microwave transmission line loss.
5. Microcalorimeter microwave connector loss.
6. Bolometer mount microwave leakage.
7. Bolometer mount internal dc lead resistance.
8. Bolometer mount microwave transmission line loss.
9. Bolometer mount microwave connector loss.
10. Bolometer mount dc lead filter.
11. Microwave connector repeatability.

### 6.1 MICROCALORIMETER OPERATION THEORY

This section is based in part on formulations by both Engen [1] and Weidman [2]. Figure 6.1 is a cross section of the reference standard connected to the calorimeter isolation section and the thermopile. The figure may be helpful in understanding the following derivation and equations.

Recall that the thermopile measures the temperature rise of the attached bolometer mount when the mount is biased with dc alone, or with dc plus rf. The expression for the thermopile output voltage with only dc bias applied to the mount may be written as

$$e_1 = k_1 P_{dcI} = \frac{k_1 V_1^2}{R_0}, \quad (6-1)$$

where  $k_1$  is a proportionality factor characteristic of the thermal transfer path from the mount to the thermopile and is a constant unless the thermopile output is nonlinear. The other terms were originally defined in section 1.2.  $P_{dcI}$  is the dc bias power dissipated in the mount,  $V_1$  is the power meter output

voltage (equal to the voltage across the bolometer elements) when  $P_{dc1}$  is applied, and  $R_o$  is the bolometer element dc operating resistance maintained by the power meter.

With both dc and rf applied to the mount, the new thermopile output voltage is given by

$$e_2 = k_2 \left( P_{dc2} + aP_t + bP_{mi} + cP_{ci} + dP_{mb} \right) \quad (6-2)$$

where  $k_2$  does not equal  $k_1$  because of the thermopile nonlinearity,  $P_{dc2}$  is the dc bias power dissipated in the mount,  $P_t$  is the rf dissipation in and near the thermistor beads,  $P_{mi}$  is the rf loss in the mount input section transmission line including the connector,  $P_{ci}$  is the rf loss in the calorimeter isolation section transmission line including the connector,  $P_{mb}$  is the rf loss in the mount rf low-pass filters, and  $a$ ,  $b$ ,  $c$ , and  $d$  are constants that account for thermal paths that are different than the one described by  $k_2$ . Equation (6-2) may also be written as

$$e_2 = k_2 \left[ P_{dc2} + P_{rf} \left( a \frac{P_t}{P_{rf}} + b \frac{P_{mi}}{P_{rf}} + c \frac{P_{ci}}{P_{rf}} + d \frac{P_{mb}}{P_{rf}} \right) \right], \quad (6-3)$$

where  $P_{rf}$  is the total rf power delivered to the mount. Letting

$$q = P_t / P_{rf}, \quad (6-4)$$

$$r = P_{mi} / P_{rf}, \quad (6-5)$$

$$s = P_{ci} / P_{rf}, \quad (6-6)$$

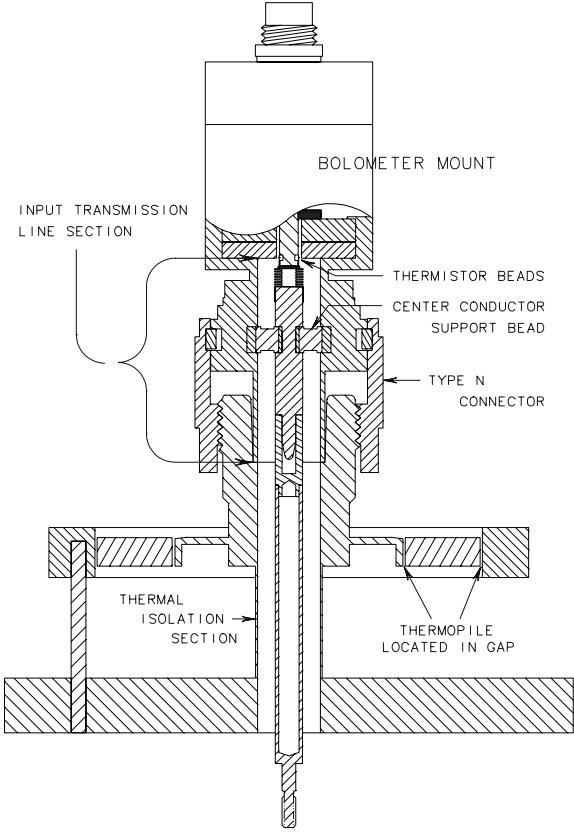


Figure 6.1 Cross section of mount and calorimeter.

and

$$t = P_{mb} / P_{rf}, \quad (6-7)$$

we can write eq (6-3) as

$$e_2 = k_2 [P_{dc2} + P_{rf}(aq + br + cs + dt)]. \quad (6-8)$$

Note that

$$q + r + t = 1 \quad (6-9)$$

because each term represents a fraction of the total rf power absorbed in the mount.

Then eq (6-8) can be written as

$$e_2 = k_2 (P_{dc2} + g P_{rf}), \quad (6-10)$$

where  $g$  is the correction factor given by

$$g = aq + br + cs + dt. \quad (6-11)$$

Writing eq (6-10) in terms of  $V_2$  gives

$$e_2 = k_2 \left( \frac{V_2^2}{R_0} + g P_{rf} \right). \quad (6-12)$$

Solving for  $P_{rf}$ , we find

$$P_{rf} = \frac{1}{g} \left( \frac{e_2}{k_2} - \frac{V_2^2}{R_0} \right). \quad (6-13)$$

From eq (6-1),  $k_l$  is given by

$$k_1 = \frac{e_1 R_0}{V_1^2}. \quad (6-14)$$

Let

$$k_2 = c_n k_1 = c_n \frac{e_1 R_0}{V_1^2}, \quad (6-15)$$

where  $c_n$  is a correction factor for the thermopile nonlinearity. Using eq (6-15), eq (6-13) becomes

$$P_{rf} = \frac{1}{g} \left[ \left( \frac{e_2}{e_1} \right) \frac{V_1^2}{R_0 c_n} - \frac{V_2^2}{R_0} \right] \quad (6-16)$$

or

$$P_{rf} = \frac{1}{g} \left( \frac{V_1^2}{R_0} \right) \left[ \left( \frac{e_2}{e_1} \right) \frac{1}{c_n} - \left( \frac{V_2}{V_1} \right)^2 \right]. \quad (6-17)$$

The definition of effective efficiency is

$$\eta_e = \frac{P_b}{P_{rf}}, \quad (6-18)$$

where  $P_b$  is the bolometric substituted power given by

$$P_b = \frac{1}{R_0} \left( V_1^2 - V_2^2 \right) = \frac{V_1^2}{R_0} \left[ 1 - \left( \frac{V_2}{V_1} \right)^2 \right], \quad (6-19)$$

and  $P_{rf}$  is the total rf power delivered to the mount.

Using eqs (6-17) and (6-19), eq (6-18) becomes

$$\eta_e = g \frac{1 - \left( \frac{V_2}{V_1} \right)^2}{\frac{e_2}{e_1} \frac{1}{c_n} - \left( \frac{V_2}{V_1} \right)^2}. \quad (6-20)$$

Equation (6-20) can be simplified by letting

$$F_V = \frac{V_2}{V_1} \quad (6-21)$$

and

$$f_e = \frac{e_2}{e_1} \frac{1}{c_n}, \quad (6-22)$$

so eq (6-20) becomes

$$\eta_e = g \frac{1 - F_V^2}{f_e - F_V^2}. \quad (6-23)$$

Taking the total differential of eq (6-23) gives an expression for the uncertainty  $\Delta\eta_e$  in  $\eta_e$  due to uncertainties in  $g$ ,  $F_V$ , and  $f_e$ .

$$|\Delta\eta_e| = \frac{1 - F_V^2}{f_e - F_V^2} |\Delta g| + g \left| \frac{2 F_V (1 - f_e)}{(f_e - F_V^2)^2} \right| |\Delta F_V| + g \frac{1 - F_V^2}{(f_e - F_V^2)^2} |\Delta f_e|, \quad (6-24)$$

where the absolute value of each uncertainty term is used to obtain the maximum uncertainty. The relative uncertainty is given by

$$\left| \frac{\Delta\eta_e}{\eta_e} \right| = \left| \frac{\Delta g}{g} \right| + \frac{2 F_V^2 (f_e - 1)}{(1 - F_V^2)(f_e - F_V^2)} \left| \frac{\Delta F_V}{F_V} \right| + \frac{f_e}{f_e - F_V^2} \left| \frac{\Delta f_e}{f_e} \right|. \quad (6-25)$$

The determination of the terms  $g$ ,  $F_V$ , and  $f_e$ , and their uncertainties, is described in the following sections.

## 6.2 DETERMINATION OF CORRECTION FACTOR $g$

Figure 6.2 is a cross section of a special measurement configuration used to determine  $g$ . The setup contains two thermopile assemblies and is symmetrical about the indicated horizontal center line. The microwave losses and the thermal conditions in each half are nearly equal, so the effect on the thermopiles is as if the other half were not present. (An analogy is the method of images employed with electromagnetic field problems.) Each half of the center adapter section is made of the same material and length as the input transmission line section of the mount (see figure 6.1), so that each half is thermally and electrically the same as a mount connector and input section. Although not shown, the transmission line is terminated (at the top of the figure) by one of the reference standards. The arrangement is fed by a nominal 10 mW (with the power leveled by the terminating mount) from the bottom, and the output of both thermopiles is noted. Assuming adequate symmetry, either thermopile reading is an indication of the heating due to loss in the calorimeter thermal isolation section and the mount input section. In the same way, then, as eqs (6-1) and (6-2) were developed, one of the thermopile outputs (say the lower) can be written as

$$e_B = k_B(b' P_{mi} + c' P_{ci}). \quad (6-26)$$

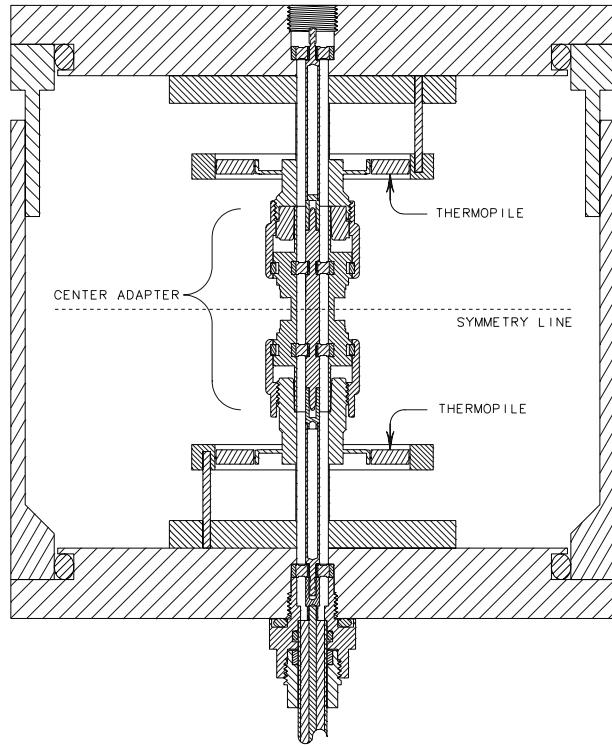


Figure 6.2 Arrangement used to determine the correction factor  $g$ .

As before,  $P_{mi}$  is the loss in the mount input section, and  $P_{ci}$  is the loss of the calorimeter thermal isolation section, and  $k_B$ ,  $b'$ , and  $c'$  are equivalent to  $k_i$ ,  $b$ , and  $c$ , the constants characteristic of the different thermal transfer paths. Note that although the total loss in this measurement configuration is approximately double that of the configuration of figure 6.1, it does not result in added heating because there is also an additional identical thermal path to the temperature-controlled external environment.

In terms of the power ratios of eqs (6-5) and (6-6), eq (6-26) becomes

$$e_B = k_B P_{rf} (b' r + c' s). \quad (6-27)$$

Because of the adapter material and size, we assume that

$$k_B \approx k_1. \quad (6-28)$$

The factor  $b'$  is associated with the loss in the mount input section. In the mount, the heat due to center conductor loss is transmitted to the thermopile primarily by the center conductor support bead rather than by the thermistor bead structure, because the dc blocking capacitor and bellows contact provide good thermal isolation. This was verified experimentally by measuring the thermopile output with the bellows and capacitor removed from a mount. For a representative mount with a dc bias of about 30 mW, the thermopile output with the bellows is  $116 \mu\text{V}$ , and without the bellows the output is  $118 \mu\text{V}$ , a less than 2 percent change. Thus the thermal effect should be nearly the same in the adapter and

$$b' \approx b. \quad (6-29)$$

The factor  $c'$  is associated with the loss of the calorimeter isolation section, and for the same reasons noted above,

$$c' \approx c. \quad (6-30)$$

With these substitutions eq (6-27) becomes

$$e_B \approx k_1 P_{rf} (br + cs), \quad (6-31)$$

so

$$br + cs \approx \frac{e_B}{k_1 P_{rf}}. \quad (6-32)$$

Recall that

$$g = aq + br + cs + dt. \quad (6-11)$$

The loss in the low pass filters is given by  $t$ . It will be zero only if there is no rf leakage past the internal thermistor bead structure. It is assumed that  $t$  is negligible, since its effect can be absorbed in the other loss term  $q$ , and it is not susceptible to direct measurement. The approximation that  $a \approx 1$  can be made because  $q$  is the power ratio associated with the dissipation in the thermistor beads and  $k_1$  is the thermal

constant associated with that same heating. Then, with (6-32) substituted into (6-11), the expression for  $g$  becomes

$$g = q + \frac{e_B}{k_1 P_{rf}}. \quad (6-33)$$

From eq (6-9), with  $t = 0$ ,

$$q = 1 - r. \quad (6-34)$$

Recall that  $r$  is the fractional loss in the input section and connector of the mount. An approximation for this is half the loss of the adapter section shown in figure 6.2. If the total loss is  $\alpha_L$ , then

$$q \approx 1 - \frac{\alpha_L}{2}. \quad (6-35)$$

That loss is given by (see appendix A)

$$\alpha_L \approx 1 - |S_{21}|^2, \quad (6-36)$$

so the expression for  $g$  becomes

$$g \approx \frac{1 + |S_{21}|^2}{2} + \frac{e_B}{k_1 P_{rf}}. \quad (6-37)$$

Measured and calculated values for  $|S_{21}|$  in decibels are shown in figure 6.3. The basis for the "theoretical plated line loss" curve is given in appendix B. The curve labeled "adjusted plated line loss" is a calculated loss obtained by changing the value of the conductivity of the gold plating and the joint loss factors (including the exponent of the frequency term) so the curve approximately fits the measured values.

Table 6.1 lists the parameter values that were changed to obtain the adjusted curve

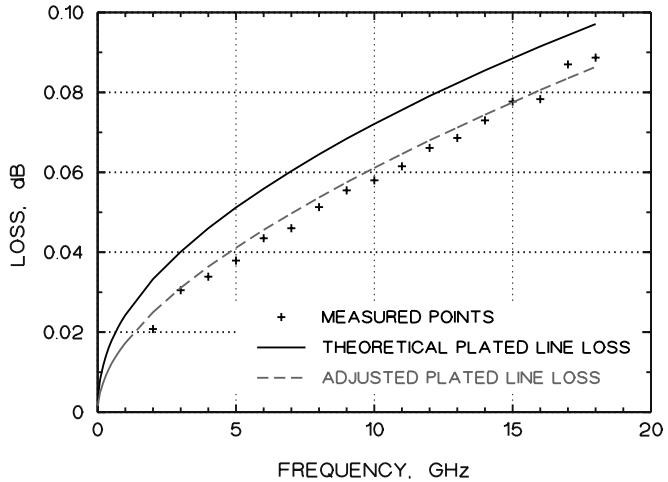


Figure 6.3 Type N male-to-male coax adapter loss.

Table 6.1 Values used in calculating the adjusted loss.

Parameter	Layer 1 (Au) thickness	Layer 1 (Au) conductivity	Layer 2 (Cu) conductivity	Joint loss factors		
	$d$ $\mu\text{m}$	$\sigma_1$ S/m	$\sigma_2$ S/m	$A_0$	$B$ dB/(GHz) <sup>E</sup>	$E$
Inner conductor loss calculation	1.27 (nc)	$2.5 \times 10^7$	$8.00 \times 10^6$ (nc)	—	—	—
Outer conductor loss calculation	1.27 (nc)	$2.5 \times 10^7$	$5.75 \times 10^7$ (nc)	—	—	—
Type N joint loss calculation	—	—	—	0 (nc)	0.004	0.65
Bead joint loss calculation	—	—	—	0 (nc)	0.0022	0.65

(compare with table B1 in appendix B) using the equations derived in appendix B. An (nc) indicates the values have not changed from those listed in table B1.

The adjusted curve provides reasonable low frequency values for  $|S_{21}|$  below 2 GHz where it was not possible to measure it. These values are used in eq (6-37) at all frequencies below 2 GHz. Above 2 GHz the measured values of  $|S_{21}|$  are used.

Measurements of  $e_B$ , which were made over the frequency range of 10 MHz to 18 GHz, are shown in figure 6.4. The dashed line is a curve fitted to the bottom thermopile output. It shows that the output has a  $\sqrt{f}$  dependence. The  $e_B$  values from the bottom thermopile are used in the calculation of  $g$  using eq (6-37).

The value used for  $P_{rf}$  in eq (6-37) can reasonably be the nominal 10 mW power at which  $e_B$  was measured.

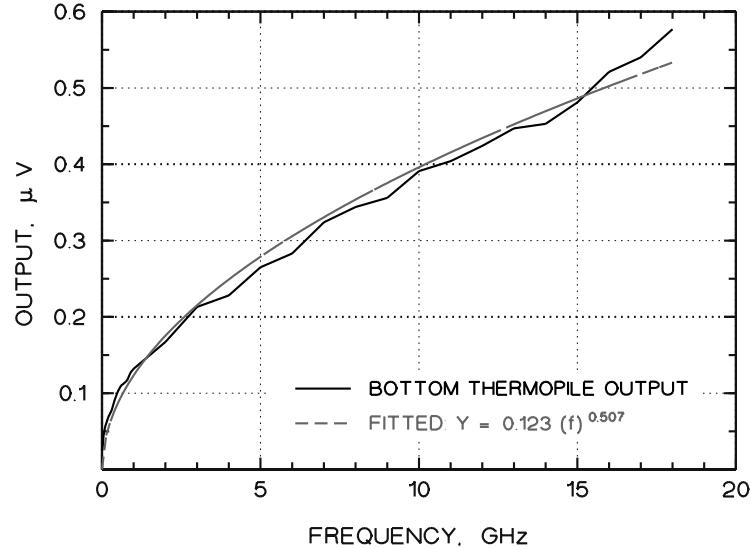


Figure 6.4 Measured thermopile output.

Values for  $g$  as a function of frequency from 10 MHz to 18 GHz are shown in figure 6.5. The fitted curve is proposed as the operational expression for  $g$ . A numerical listing of the values for  $g$  is included as table 6.2.

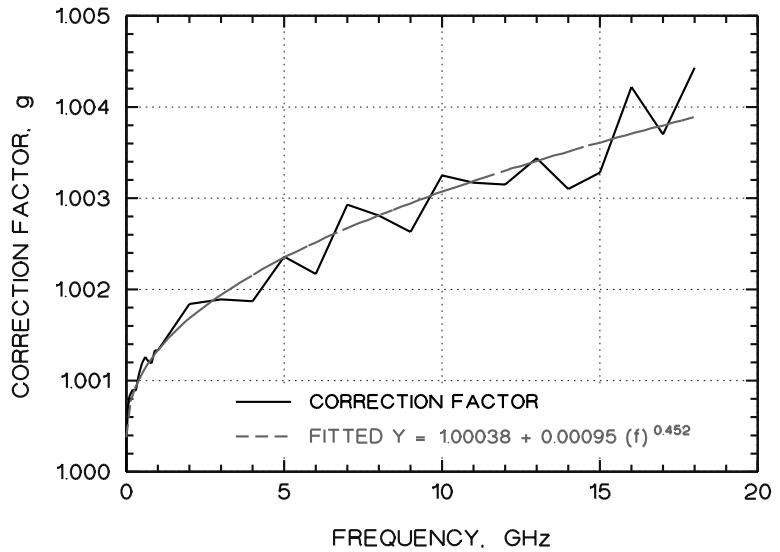


Figure 6.5 Microcalorimeter correction factor,  $g$ .

It is mathematically possible for  $g$  to be less than 1 if

$$\frac{\alpha_L}{2} > \frac{e_B}{k_1 P_{rf}}. \quad (6-38)$$

Physically, this can happen because the heating effect of the center conductor loss is relatively isolated from the thermopile. In a waveguide calorimeter there is not an equivalent thermal path that is fairly well isolated from the thermopile, so  $g$  must always be 1 or greater.

Table 6.2 Tabulated values for  $g$ .

FREQ GHz	$q$	$\frac{e_B}{k_1 P_{rf}}$	$g$	$g$ fitted
0.01	0.99983	0.00063	1.00046	1.00050
0.02	0.99975	0.00073	1.00048	1.00054
0.03	0.99969	0.00084	1.00052	1.00057
0.04	0.99964	0.00099	1.00063	1.00060
0.05	0.99960	0.00111	1.00071	1.00063
0.06	0.99955	0.00119	1.00074	1.00065
0.07	0.99951	0.00124	1.00075	1.00067

Table 6.2 (continued) Tabulated values for  $g$ .

FREQ GHz	$q$	$\frac{e_B}{k_1 P_{rf}}$	$g$	$g$ fitted
0.08	0.99947	0.00129	1.00076	1.00068
0.09	0.99944	0.00134	1.00078	1.00070
0.10	0.99941	0.00142	1.00083	1.00072
0.20	0.99915	0.00175	1.00090	1.00084
0.30	0.99894	0.00195	1.00089	1.00093
0.40	0.99877	0.00230	1.00107	1.00101
0.50	0.99861	0.00258	1.00119	1.00107
0.60	0.99847	0.00278	1.00126	1.00113
0.70	0.99834	0.00286	1.00121	1.00119
0.80	0.99823	0.00296	1.00119	1.00124
0.90	0.99812	0.00322	1.00133	1.00129
1.00	0.99801	0.00332	1.00133	1.00133
2.00	0.99763	0.00423	1.00186	1.00186
3.00	0.99654	0.00539	1.00193	1.00194
4.00	0.99615	0.00577	1.00192	1.00216
5.00	0.99570	0.00671	1.00241	1.00235
6.00	0.99507	0.00716	1.00224	1.00252
7.00	0.99481	0.00820	1.00301	1.00267
8.00	0.99421	0.00871	1.00292	1.00281
9.00	0.99378	0.00901	1.00279	1.00294
10.0	0.99347	0.00990	1.00337	1.00307
11.0	0.99307	0.01023	1.00330	1.00319
12.0	0.99258	0.01073	1.00332	1.00330
13.0	0.99227	0.01132	1.00358	1.00341
14.0	0.99179	0.01147	1.00326	1.00351
15.0	0.99128	0.01218	1.00346	1.00361
16.0	0.99119	0.01319	1.00438	1.00371
17.0	0.99022	0.01367	1.00389	1.00380
18.0	0.99008	0.01461	1.00469	1.00389

### 6.3 UNCERTAINTY IN CORRECTION FACTOR $g$

From the preceding section

$$g \approx \frac{1 + |S_{21}|^2}{2} + \frac{e_B}{k_1 P_{rf}}. \quad (6-37)$$

Taking the total differential of eq (6-37) gives the following expression for the absolute uncertainty in  $g$  due to uncertainties in the independent variables.

$$|\Delta g| = |S_{21}|^2 \left| \frac{\Delta S_{21}}{S_{21}} \right| + \frac{1}{k_1 P_{rf}} |\Delta e_B| + \frac{e_B}{k_1 P_{rf}} \left| \frac{\Delta k_1}{k_1} \right| + \frac{e_B}{k_1 P_{rf}} \left| \frac{\Delta P_{rf}}{P_{rf}} \right|, \quad (6-39)$$

where the absolute value of each uncertainty term is used to obtain the maximum uncertainty.

In the measurement of both  $e_B$  and  $k_1$  a correction for the zero offset is made. In terms of the measured quantities these are given by

$$e_B = (e_B)_1 - (e_B)_0 \quad (6-40)$$

and

$$k_1 = \frac{(e_{k_1})_1 - (e_{k_1})_0}{P_{dcI}}, \quad (6-41)$$

where the subscript <sub>0</sub> denotes the zero correction value and the subscript <sub>1</sub> the measured value. The variable  $P_{dcI}$  is the dc power dissipated in the thermistor mount. Thus the ratio of  $e_B$  to  $k_1$  includes a ratio of zero-corrected nanovoltmeter readings.

$$\frac{e_B}{k_1} = \frac{(e_B)_1 - (e_B)_0}{(e_{k_1})_1 - (e_{k_1})_0} P_{dcI}. \quad (6-42)$$

As will be explained in the next section, under these circumstances only the random part of the nanovoltmeter error contributes to the uncertainty.

Rather than using analytical differentiation, the uncertainty in  $g$  has been evaluated numerically. The contribution of each variable is determined by first calculating  $g$  with no change in the variable, and then again with the variable at its uncertainty limit, all other variables held constant. The difference between these two values of  $g$  gives the uncertainty due to the effect of that variable. This process is repeated for each variable, with the total uncertainty given by the sum of these individual contributions. As eq (6-25) shows, the relative uncertainty in  $\eta_e$  due to  $g$  is just the relative uncertainty in  $g$ .

Table 6.3 gives the uncertainty used for each variable along with the basis for the choice. The value shown is either the equivalent of one standard deviation of a normal distribution (as indicated by an SD) or the half-width limit of a rectangular distribution (as indicated by an R).

Table 6.3. Variable uncertainty values.

Uncertainty	Value	Basis
$ \Delta e_B $	6 nV (SD)	Random error of two $e$ measurements (each is average of 18, see section 6.4)
$\left  \frac{\Delta k_1}{k_1} \right $	0.01 (R)	Approximation $k_1 \approx k_B$ plus measurement error
$\left  \frac{\Delta P_{rf}}{P_{rf}} \right $	0.01 (R)	Bolometric power measurement plus power level instability
$\left  \frac{\Delta S_{21}}{S_{21}} \right $	1 (SD)	Below 0.2 GHz ( $ S_{21} $ from fitted curve)
$ \Delta S_{21} $	0.0076 dB (SD)	For 0.3 through 1 GHz ( $ S_{21} $ from fitted curve)
$ \Delta S_{21} $	Function of frequency (SD) (see figure 6.6)	Above 1 GHz: 6-port measurement uncertainty given by: $u_{S21} = \sqrt{\Delta^2/3 + S_{NIST}^2 + S_c^2/6}$ where $\Delta = 0.0006\sqrt{f} + 0.0011$ $S_{NIST} = 10^{-2.17 + 0.024f}$ $S_c = 10^{-3.22 + 0.034f}$

The contribution of the individual factors to the uncertainty in  $g$  as a function of frequency is shown in figure 6.6. The contribution from the level instability is identical to that of  $k_1$ . That the end points of the curves seem to meet is only coincidence. By far the largest uncertainty is from the 6-port measurement of the adapter loss. These components are combined as part of the expanded uncertainty as described in section 6.9.

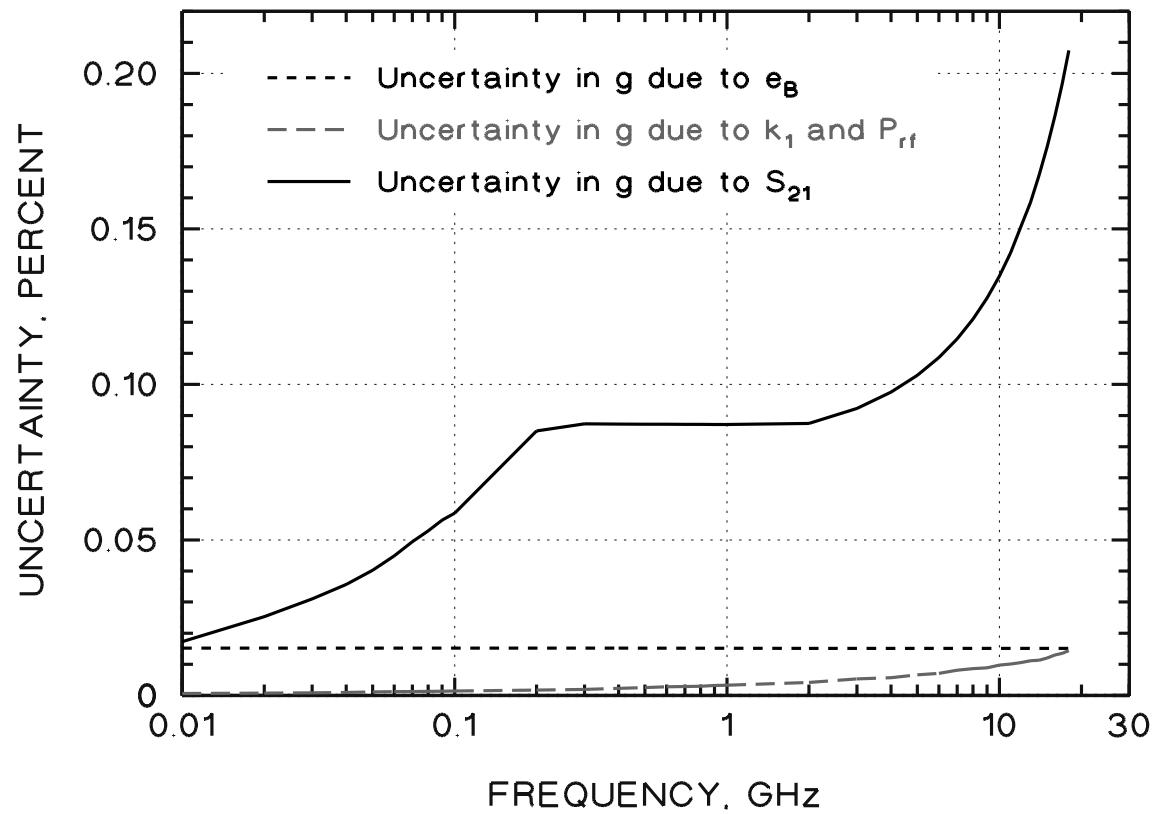


Figure 6.6 Contribution of each factor to the uncertainty in  $g$ .

## 6.4 UNCERTAINTY DUE TO VOLTAGE RATIOS

### 6.4.1 Power Meter Voltage Ratio

From section 6.1, the expression for  $F_V$  is

$$F_V = \frac{V_2}{V_1}. \quad (6-21)$$

The absolute value of the uncertainty in  $F_V$  is

$$|\Delta F_V| = \frac{V_2}{V_1^2} |\Delta V_1| + \frac{1}{V_1} |\Delta V_2|. \quad (6-43)$$

Because of mount drift,  $V_1$  does not remain constant during the measurement, so  $V_1$  is actually an interpolated value between two end point measurements.  $V_1$  is given by

$$V_1 = V_{1i} + F(V_{1f} - V_{1i}), \quad (6-44)$$

where  $V_{1i}$  and  $V_{1f}$  are the initial and final values of the  $V_1$  measurements and  $F$  is a fraction between 0 and 1. The uncertainty in  $V_1$  is

$$|\Delta V_1| = (1-F) |\Delta V_{1i}| + F |\Delta V_{1f}|. \quad (6-45)$$

If both the initial and final values are measured on the same range,  $|\Delta V_{1i}| \approx |\Delta V_{1f}|$ . Then by eq (6-45),  $|\Delta V_1| \approx |\Delta V_{1i}|$ , so the uncertainty in  $V_1$  is the same as for a single measurement.

For both the power meter voltages ( $V$ ), and the nanovoltmeter readings ( $e$ ), the desired quantity is a ratio. The error in a voltmeter reading is generally specified as a percent of reading factor (alpha) plus a percent of full scale (beta). The alpha factor comes from the error of the internal reference, while the beta factor is due to random and zero correction errors and nonlinearity. In a ratio measurement, if the two voltages are measured on the same scale, the alpha factor can be neglected. In addition, if the zero drift is explicitly corrected (as in the  $f_e$  case), the only contribution to the uncertainty is from the random part of the beta factor.

A calculation of the uncertainty in  $\eta_e$  due to  $\Delta F_V$ , which is a function of  $\eta_e$  and  $P_{rf}$ , can be made using eqs (6-25) and (6-43). If the voltmeter manufacturer's one-year beta specification is used, the result is a value well under 0.001 percent for all reasonable values of  $\eta_e$ .

### 6.4.2 Thermopile Voltage Ratio

The expression for  $f_e$  is

$$f_e = \frac{e_2}{e_1} \frac{1}{c_n}. \quad (6-22)$$

In measuring  $f_e$ , a correction for the zero offset must be made. This involves measuring  $e$  before measuring the dc bias term  $e_1$  or the dc-plus-rf term  $e_2$ . When we take  $e_0$  into consideration, eq (6.1.22) becomes

$$f_e = \frac{1}{c_n} \frac{e_2 - e_0}{e_1 - e_0}. \quad (6-46)$$

The absolute uncertainty in  $f_e$  is given by

$$|\Delta f_e| = \frac{e_2 - e_1}{c_n(e_1 - e_0)^2} |\Delta e_0| + \frac{e_2 - e_0}{c_n(e_1 - e_0)^2} |\Delta e_1| + \frac{1}{c_n(e_1 - e_0)} |\Delta e_2| + \frac{e_2 - e_0}{c_n^2(e_1 - e_0)} |\Delta c_n|. \quad (6-47)$$

Like  $V_1$ ,  $e_1$  is obtained by linear interpolation, so the uncertainty  $\Delta e_1$  is also that of a single measurement.

The calculation of the uncertainty in  $\eta_e$  due to  $\Delta f_e$  is based on the applicable parts of eq (6-25) and eq (6-47). To determine the error in  $f_e$  it is necessary to know the random error in the nanovoltmeter measurement. This random error beta factor is determined by making repeated measurements on the actual setup and thus includes the effects of variations in the dc bias as supplied by the power meter, in the microwave power leveling, in the external temperature, and in the room air pressure. These measurements were made under three conditions: with no dc bias, with dc bias, and with dc bias plus rf at 18 GHz. The largest standard deviation seen was 3.65 nV for the dc-plus-rf case, and that result is shown in figure 6.7. The three-sigma limit is therefore about  $\pm 11$  nV.

In the actual efficiency measurement routine, each data point is the average of 18 separate measurements, so the value for  $\Delta f_e$  can be further decreased as a result of the averaging. This reduces the three-sigma limit by a factor of  $1/\sqrt{18}$  to approximately  $\pm 3$  nV. Using a value of  $\pm 3$  nV for  $\Delta e_0$  and  $\Delta e_1$  in eq (6-47) and then using that result in eq (6-25) gives the uncertainty in  $\eta_e$  due to  $\Delta f_e$  shown in figure 6.8. The uncertainty is a function  $\eta_e$  and  $P_{rf}$  but not of frequency. The maximum is about 0.016 percent when  $\eta_e$  is 1. That value is used as the thermopile voltage ratio uncertainty.

An additional factor that may add to  $\Delta f_e$  is the uncertainty in knowing when the thermopile has reached equilibrium. This is a critical element in the measurement. A software algorithm determines when equilibrium has been reached at each measurement frequency. The algorithm is described in appendix C. It has been tested by letting the measurement continue for several minutes beyond the point the algorithm indicates stability has been reached and noting that the result essentially does not change. While it has not been possible to detect any systematic uncertainty in the process, there is a random component and that is included in the random uncertainty number.

#### 6.4.3 Thermopile and Nanovoltmeter Nonlinearity

The linearity correction factor  $c_n$  has been determined from a series of measurements on the Type N microcalorimeter using a mount with a resistor in place of the thermistor beads. Figure 6.9 shows the measured  $k$  as a function of the thermopile output  $e$ . Note that these results include the effect of both thermopile and nanovoltmeter nonlinearity.

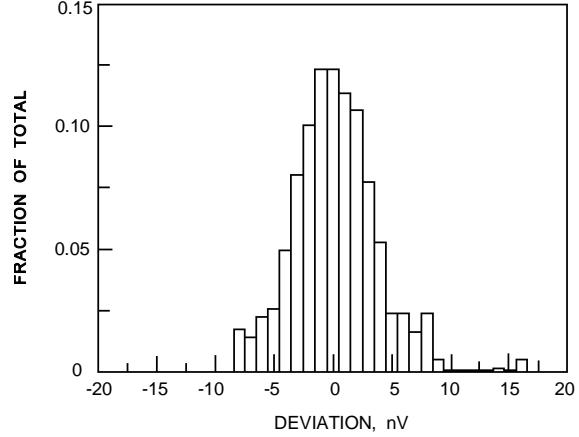


Figure 6.7. Histogram of the variation in 1000 nanovoltmeter readings. The average is  $115.916 \mu\text{V}$  with a standard deviation of  $3.65 \text{nV}$ .

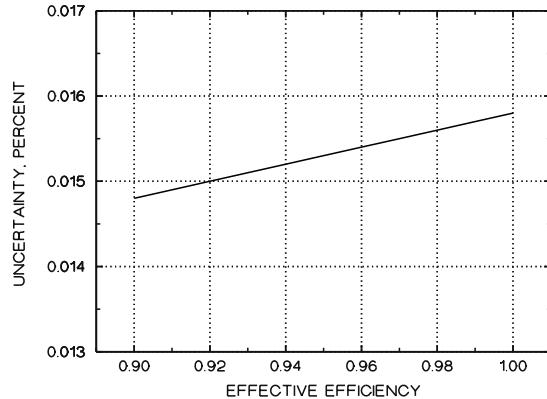


Figure 6.8. Uncertainty in  $\eta_e$  due to the thermopile voltage ratio uncertainty as a function of  $\eta_e$ .

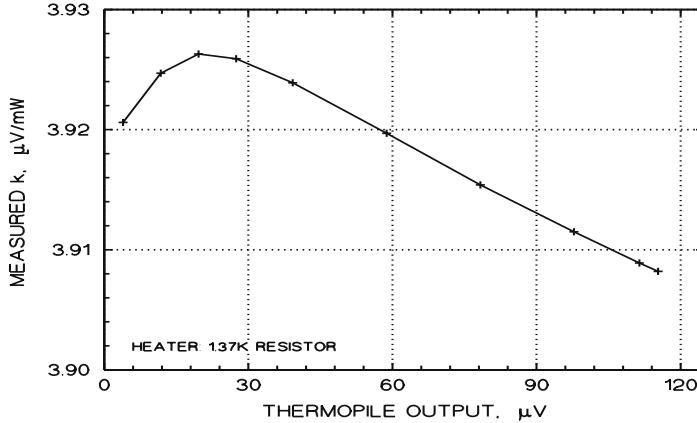


Figure 6.9.  $k$  factor vs thermopile output.

From equation (6-15),

$$k_2 = k_1 c_n. \quad (6-48)$$

$k_2$  can also be expressed as

$$k_2 = k_1 + \Delta k. \quad (6-49)$$

If  $S$  is the slope of the curve (from  $30 \mu\text{V}$  and above) in figure 6.9,

$$\Delta k \approx S (e_2 - e_1). \quad (6-50)$$

Then

$$k_2 \approx k_1 \left( 1 + \frac{S}{k_1} (e_2 - e_1) \right), \quad (6-51)$$

so

$$c_n \approx 1 + \frac{S}{k_1} (e_2 - e_1). \quad (6-52)$$

Based on experimental evidence ( $e_2 - e_1 \leq 5 \mu\text{V}$  and  $k_1 \approx 3.90$ ) and figure 6.9 ( $S \approx -0.00016$ ),  $c_n$  could vary between 1 and 0.9998. Thus the maximum correction would be on the order of 0.02 percent. Rather than make a correction, we will assume  $c_n = 1$  and include the 0.02 percent as a Type B uncertainty.

## 6.5 MOUNT MICROWAVE POWER LEAKAGE

Microwave power leakage from the mount essentially reduces the effective efficiency because the leakage energy is not detected by the mount thermistor beads. The expression for effective efficiency is

$$\eta_e = \frac{P_b}{P_{rf}}, \quad (6-18)$$

where  $P_b$  is the dc bolometric power, and  $P_{rf}$  is the net rf power delivered to the mount. Since  $P_{rf}$  is the total power dissipated in the mount plus any microwave power leakage,  $\eta_e$  includes the effect of leakage. However the microcalorimeter measures only the effect of the total power dissipated in the mount because the thermopile does not sense the leakage power. Thus the microcalorimeter measurement of  $\eta_e$  is in error if there is any leakage. To account for leakage, let the measured  $\eta_e$  be denoted by  $\eta_{eL}$ . It is given by

$$\eta_{eL} = \frac{P_b}{P_{rf} - P_L}, \quad (6-53)$$

where  $P_L$  is the leakage power. Factoring out  $P_{rf}$  gives

$$\eta_{eL} = \frac{P_b}{P_{rf} \left( 1 - \frac{P_L}{P_{rf}} \right)}. \quad (6-54)$$

Substituting from eq (6-18) and solving for  $\eta_e$  gives

$$\eta_e = \eta_{eL} \left( 1 - \frac{P_L}{P_{rf}} \right), \quad (6-55)$$

so the error in  $\eta_e$  due to  $P_L$  is  $P_L/P_{rf}$ . The ratio  $P_L/P_{rf}$  for the prototype mount was measured as described in section 2.4.1. with the result shown in figure 2.3. The ratio is less than  $-40$  dB from  $5$  MHz through  $18$  GHz. Thus the error is less than  $0.0001$  or  $0.01$  percent over that range.

## 6.6 BOLOMETER LEAD RESISTANCE

Lead resistance that is beyond the four-wire connection to the mount (in the form of any final short leads to the thermistor beads) does not cause an error in the measurement of efficiency, but does cause an error when the transfer standard is used to measure power. To determine the effect let  $r_L$  be the lead resistance. Then

$$R'_0 = R_0 - r_L = R_0 \left( 1 - \frac{r_L}{R_0} \right), \quad (6-56)$$

and

$$V' = V \left( 1 - \frac{r_L}{R_0} \right). \quad (6-57)$$

$V'$  is the actual voltage across the beads,  $V$  is the power meter voltage (known),  $R'_0$  is the actual bead resistance, and  $R_0$  is the resistance (known) being maintained by the power meter.

For the efficiency measurement the ratio of  $V_1'$  to  $V_2'$  is desired. In terms of  $V_1$  and  $V_2$  this is given by

$$\frac{V'_1}{V'_2} = \frac{V_1 \left( 1 - \frac{r_L}{R_0} \right)}{V_2 \left( 1 - \frac{r_L}{R_0} \right)} \quad (6-58)$$

which reduces to

$$\frac{V'_1}{V'_2} = \frac{V_1}{V_2} \quad (6-59)$$

and there is no error.

For the power measurement the desired expression is

$$P_b = \frac{1}{R'_0} \left( V_1'^2 - V_2'^2 \right). \quad (6-60)$$

In terms of  $V_1$  and  $V_2$ ,

$$P_b = \frac{1}{R_0} \left( V_1^2 - V_2^2 \right) \left( 1 - \frac{r_L}{R_0} \right). \quad (6-61)$$

The measurement is in error by the factor  $1 - r_L / R_0$ . Values of  $r_L$  for a commercial mount have been measured as high as 400 mΩ (including connector contact resistance because the four leads are not brought

through the connector), giving an uncertainty in the power measurement of about 0.2 percent. For the transfer standard, the residual lead resistance beyond the four-wire connection has not been measured, but is estimated as less than 10 mΩ. The error is less than 0.005 percent.

## **6.7 TYPE IV POWER METER ERRORS**

The uncertainty due to the measurement of  $V_1$  and  $V_2$  was addressed in section 6.4. The additional uncertainty due to limitations of the operational amplifiers and reference resistor within the Type IV power meter is also very small. The uncertainty is under 0.001 percent and will be neglected.

## **6.8 RANDOM EFFECTS**

The Type A evaluation of standard uncertainty for the measurement process reported in this document is based on repeated measurements of a single reference standard which will continue to be used as a check standard. Ideally, standard uncertainty for the bolometer mounts should be determined through repeat measurements for each individual mount. However, this is impractical due to the time required for a complete set of measurements. Therefore, we will assume that the standard uncertainty inherent in all mounts behaves in basically the same fashion so that the standard uncertainty we derive for the check standard mount will apply to the population of mounts as well. Although the actual measurements for the check standard mount are quite repeatable, the observed standard deviations are different for each frequency. Thus, a single value of standard uncertainty which is valid for all frequencies was calculated based on a "worst" case standard deviation.

The standard uncertainty, determined through Type A evaluation, in the measured effective efficiency for customer mounts at any individual frequency is 0.00014, which is the worst case (among frequencies) computed standard deviation based on ten degrees of freedom.

The Type A evaluation of standard uncertainty for the measured effective efficiency for the check standard mount CN05 at any individual frequency is 0.000041, which is the worst case (among frequencies) computed standard error of the mean effective efficiency,  $0.00014/\sqrt{11}$  based on ten degrees of freedom.

## 6.9 COMBINED STANDARD AND EXPANDED UNCERTAINTY

Table 6.4 is a summary of the results at 18 GHz for all the uncertainty evaluations described earlier. The section describing the uncertainty is listed in the table. Definitions for the variables and terms used are found in reference [13]. The expanded uncertainty value is for a customer standard.

Table 6.4. Value of uncertainty components in percent at 18 GHz.

Uncertainty factor (evaluation type)	Section reference	Half-width interval ( $a$ )	Distribution	Conversion formula	Standard uncertainty
Adapter loss meas. (B)	6.3	0.207	Normal	$u_i = a$	0.207
Nanovoltmeter, $e_B$ (A)	6.3	-	Normal	-	0.015
$k_1$ (B)	6.3	0.014	Rectangular	$u_i = a/\sqrt{3}$	$8.1 \times 10^{-3}$
Power leveling & meas. (B)	6.3	0.014	Rectangular	$u_i = a/\sqrt{3}$	$8.1 \times 10^{-3}$
V ratio, $F_V$ (B)	6.4.1	0.001	Rectangular	$u_i = a/\sqrt{3}$	$5.8 \times 10^{-4}$
e ratio, $f_e$ (A)	6.4.2	-	Normal	-	0.016
Linearity, $c_n$ (B)	6.4.3	0.02	Rectangular	$u_i = a/\sqrt{3}$	0.012
Mount leakage (B)	6.5	0.01	Rectangular	$u_i = a/\sqrt{3}$	$5.8 \times 10^{-3}$
Lead resistance (B)	6.6	0.005	Rectangular	$u_i = a/\sqrt{3}$	$2.9 \times 10^{-3}$
Type IV power meter (B)	6.7	0.001	Rectangular	$u_i = a/\sqrt{3}$	$5.8 \times 10^{-4}$
Random effects (A)	6.8	-	Normal	-	0.014
Combined standard uncertainty (RSS)					0.209
Expanded uncertainty ( $k = 2$ )					0.419

The first factor on the list is the largest, and because of the RSS combination, dominates the combined uncertainty. It is also the only uncertainty that is a strong function of frequency.

Figure 6.10 shows the expanded uncertainty as a function of frequency. It also shows a fitted curve with the equation that is the operational expression for the expanded uncertainty. The uncertainty at any frequency is calculated using the equation. The higher value it gives in the range 50 to 200 MHz is intentional and accounts for low frequency dissipation in the mount that occurs in the low pass filter

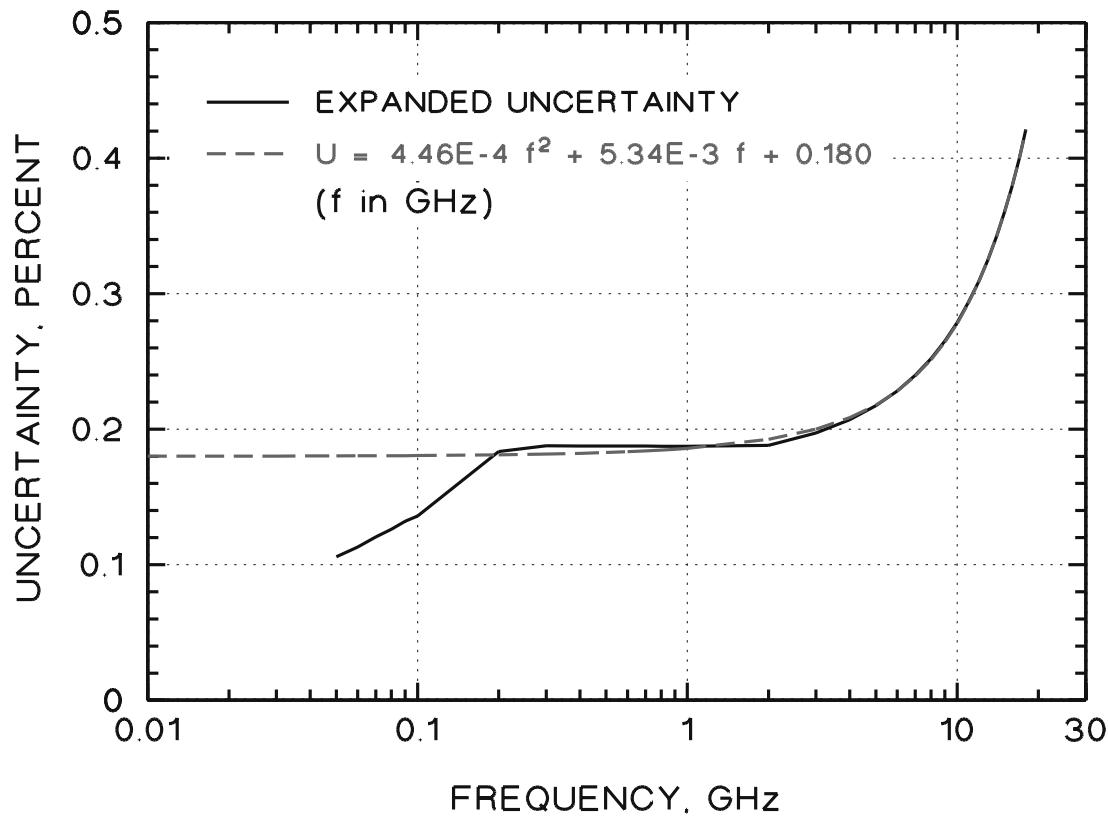


Figure 6.10 The expanded uncertainty ( $k = 2$ ) for the Type N coaxial microcalorimeter when measuring the effective efficiency of a NIST CN coaxial transfer standard.

behind the thermistor beads. This process has become apparent in using and comparing the CN mount with other transfer standards, but we have not been able to come up with any way evaluate it directly.

A sample Report of Calibration is found in appendix E.

## 7. MEASUREMENT ASSURANCE

One of the most important aspects of maintaining the coaxial microcalorimeter system is measurement assurance. Since individual mounts cannot be measured repeatedly, it becomes even more important to ensure that the system is behaving as it should. Several techniques are currently being employed to monitor the system and assure measurement quality.

To monitor the long-term behavior of the microcalorimeter system, a check standard mount is measured on a regular basis at all 125 frequencies. Each new set of measurements is compared to the historical data to determine if the system is performing as expected. Figure 7.1 summarizes the behavior of the latest observation in relation to past data. The solid dots in Figure 7.1 represent the latest observation, the diamonds denote historical data, and three standard deviation limits are indicated by a solid, vertical line at each frequency.

A second chart is used to monitor system variability at each frequency through the use of moving ranges. A moving range is defined to be the absolute value of the difference between the two most recent observations. Figure 7.2 displays the moving range, indicated by a dot, and the associated control limits based on moving ranges for the historical data, represented by a solid vertical line. If the computed moving range for the latest observation is higher than the control limit, then the process variability is greater than the acceptable amount determined by the historical data, and the cause of the increased variability should be investigated. Figures 7.1 and 7.2 indicate that the system is behaving in a reasonable fashion relative to the historical data.

Although the control charts allow us to examine the behavior of new data in comparison to past data, other methods must be used to monitor the system over time. It is impractical to generate separate control charts to monitor all 125 frequencies; however, control charts for five check frequencies are used as an additional tool for signaling potential problems, such as drift [14]. An example of the type of control charts used to monitor a check frequency is shown in figure 7.3. The top chart, called an individuals chart, monitors the nominal effective efficiency, while the bottom chart, the moving range chart, monitors variability. Although it is possible to interpret patterns in the individuals control chart, patterns observed in the moving range chart are meaningless because adjacent points are related [15]. The variability observed in the moving range chart of figure 7.3 does not exceed the upper control limit, and the newest observation on the individuals chart lies within the control limits and does not reveal any patterns or drift, so we can

conclude that the effective efficiency at a frequency of 0.1 GHz is "in control."

The five check frequencies are also used to determine the quality of mount connection before each measurement occasion using the following procedure. After each bolometer mount is connected to the coaxial calibration system, the five check frequencies are measured and the mount is disconnected. Then the same mount is reconnected to the system and the same five check frequencies are measured again. If the difference between the first and second set of measurements is small, then all 125 frequencies are measured before the mount is disconnected a second time, otherwise, the mount is disconnected, and the procedure is repeated until it can be determined that the connection is "good." The measurement assurance tools used to monitor this calibration system are quite extensive and provide confidence that the system is functioning properly.

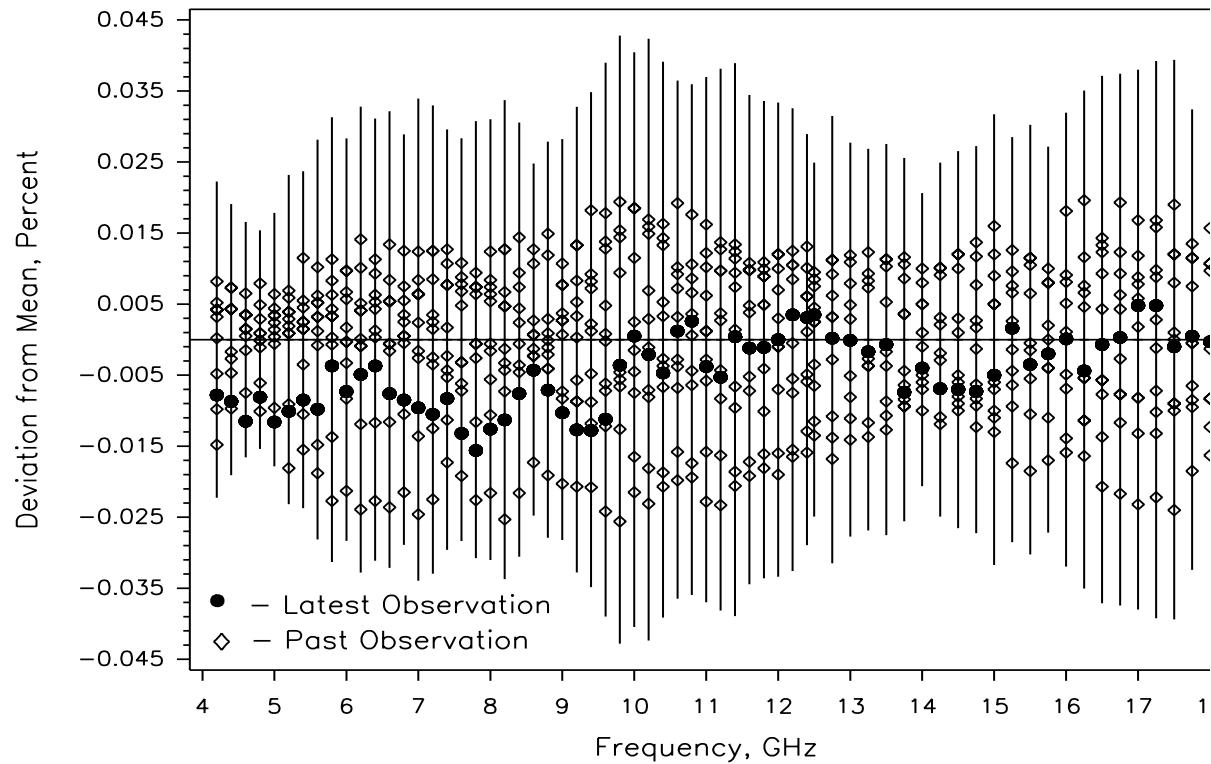
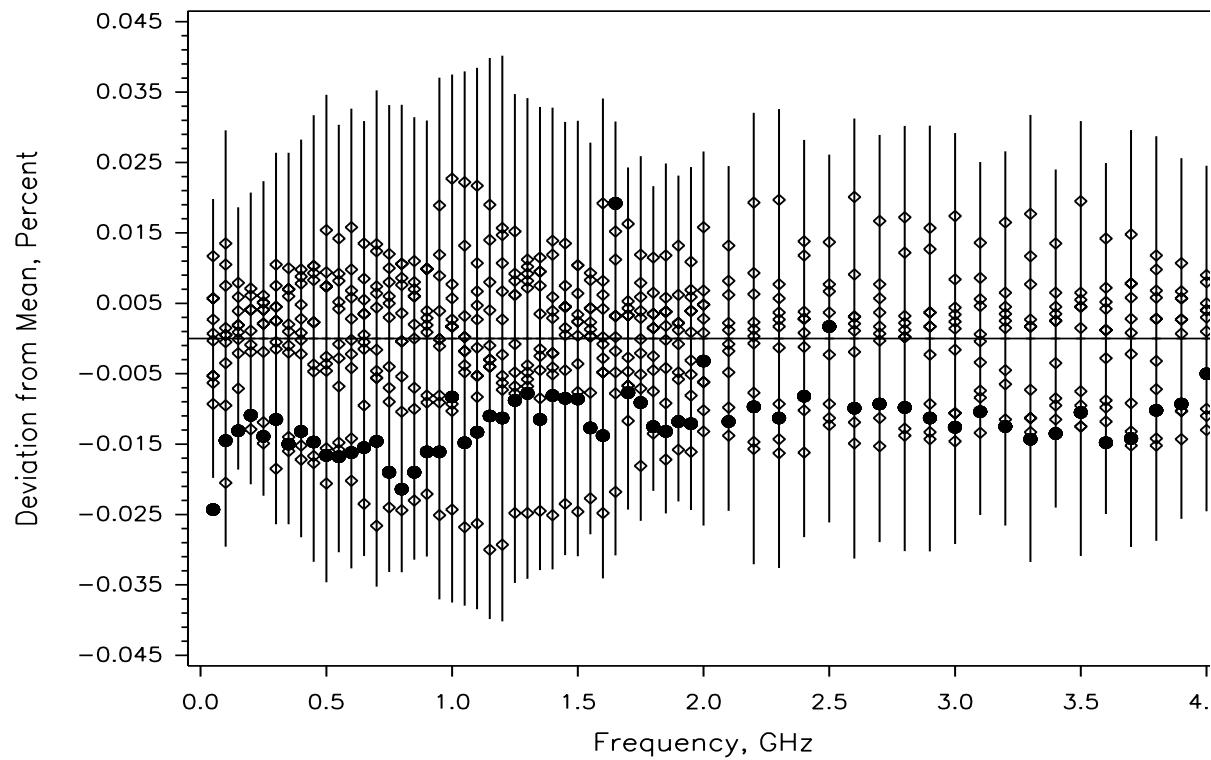


Figure 7.1. Three standard deviation limits for CN05.

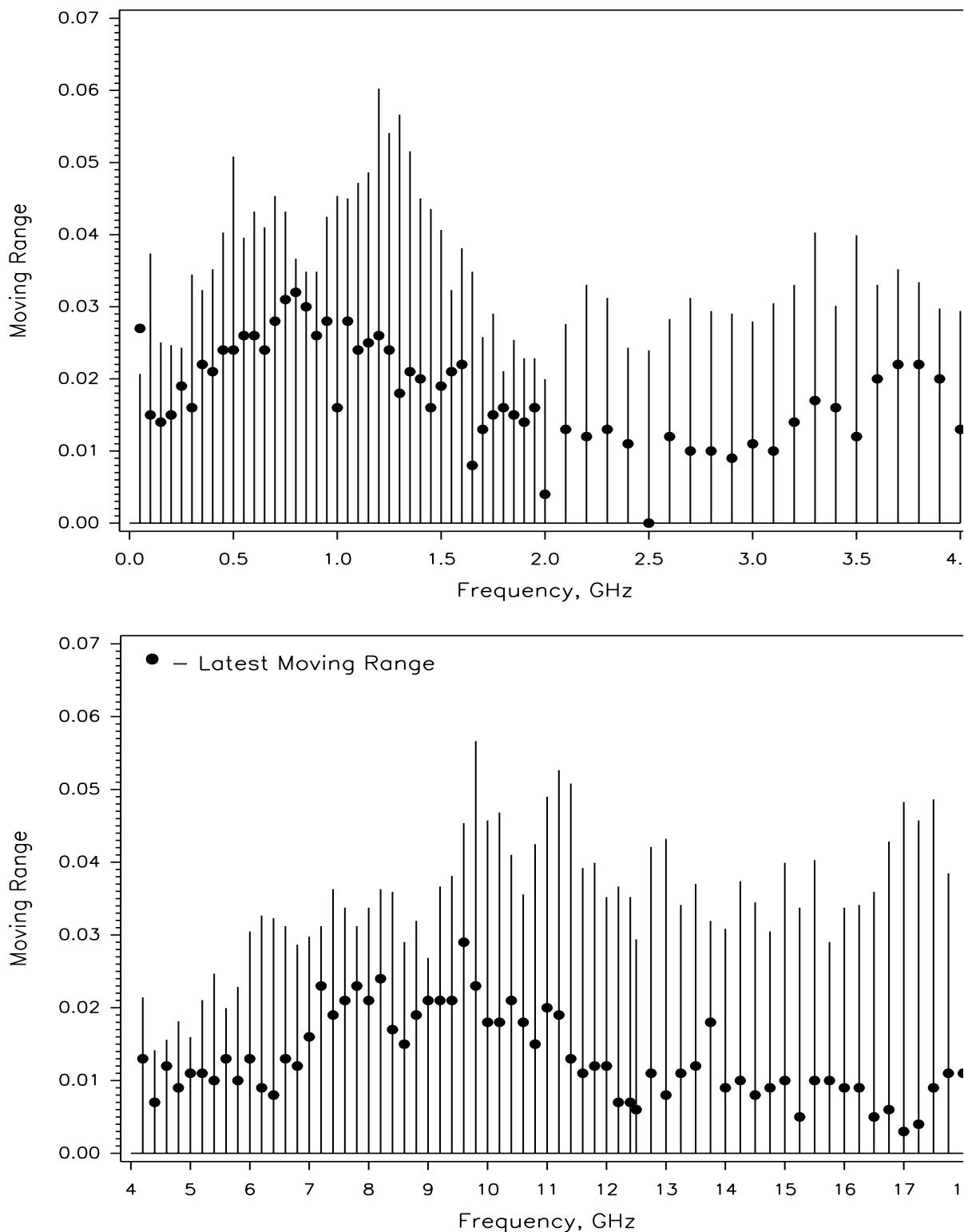


Figure 7.2. Moving range control chart for CN05.

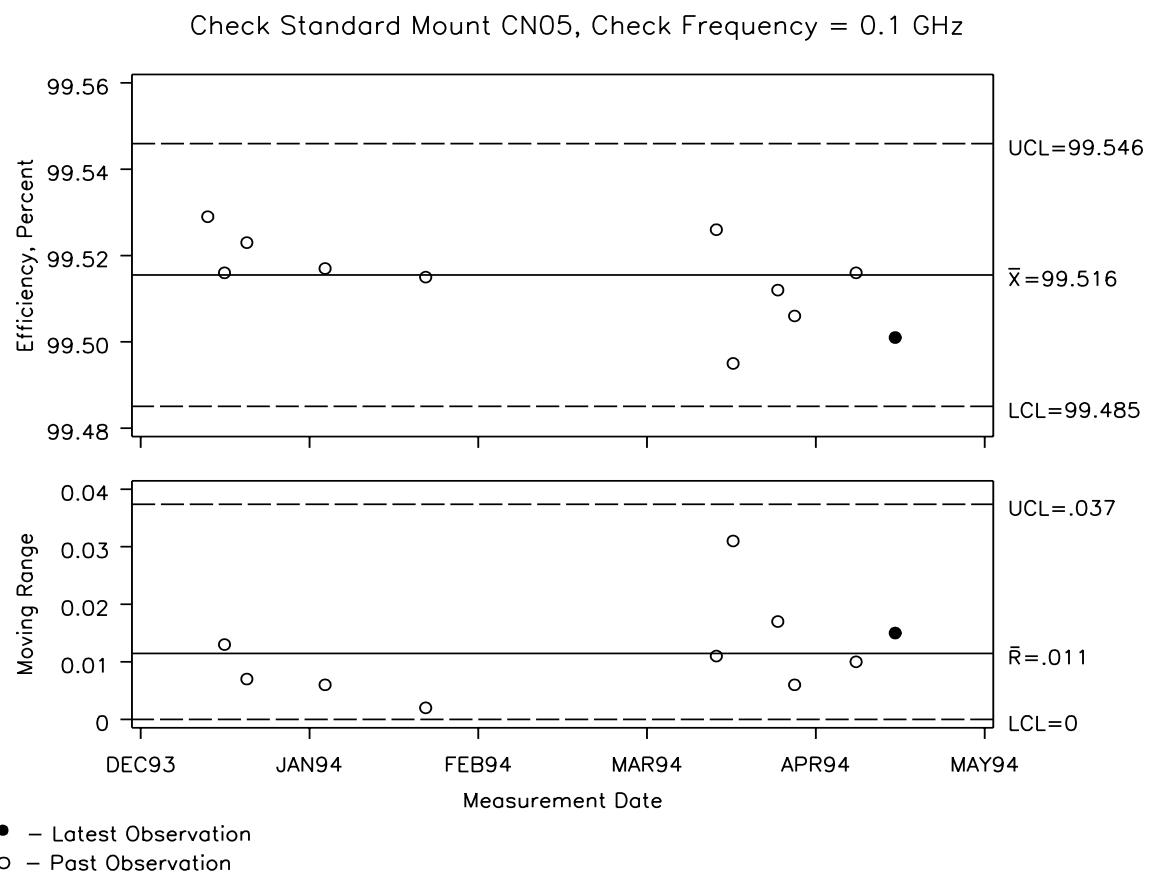


Figure 7.3. Control chart for the first of the five check frequencies.

## **8. FUTURE CHANGES**

Inevitably, in the future the calibration system will not remain exactly as described in this document. Software will be modified or even completely rewritten to improve operating efficiency or implement new measurement requirements. Hardware changes will range from the simple replacement of an obsolete or defective microwave source to a completely new way of determining the temperature change of the reference standard. Additional uncertainty or measurement assurance factors may become apparent and will have to be addressed.

The majority of the modifications will be minor. The changes will be noted and kept in an active documentation file on the system. While the details may no longer be completely accurate, this report should still adequately describe the service.

Major changes, such as a new reference standard, a new microcalorimeter design, significantly different operating procedures, large changes in uncertainty (to say one-half the present value), or changes in the frequency range, may require the preparation of a new document.

If up-to-date information is critical, contact NIST for the current documentation.

## **9. ACKNOWLEDGEMENTS**

The designs of both the coax reference standard and the coax microcalorimeter are based on the early work and ideas of Morris E. Harvey. Thanks also to Mr. Harvey for the review of his work plus his suggestions at the beginning of this project. The author is particularly indebted to Neil T. Larsen for his support, suggestions, and many helpful discussions. Special thanks to Dominic F. Veccia and Jolene D. Splett for help with the statistical analysis and experimental design contained in sections 6.8, 7, and appendix C, to Robert M. Judish for help with the uncertainty analysis and helpful comments on section 6, and also to Manly P. Weidman for his helpful suggestions on section 6.

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## 10. REFERENCES

- [1] MacPherson, A.C.; Kerns, D.M. A microwave microcalorimeter. *Rev. Sci. Instrum.* 26(1): 27-33; 1955 January.
- [2] Engen, G.F. A refined x-band microwave microcalorimeter. *J. Res. Nat. Bur. Stand. (U.S.)*. 63C(1): 77-82; 1959 July-September.
- [3] Harvey, M.E. WR 15 microwave calorimeter and bolometer unit. *Nat. Bur. Stand. (U.S.) Tech. Note* 618; 1972 May. 33 p.
- [4] Weidman, M.P.; Hudson, P.A. WR 10 millimeter wave microcalorimeter. *Nat. Bur. Stand. (U.S.) Tech. Note* 1044; 1981 June. 11 p.
- [5] Clague, F.R.; Voris, P.G. Coaxial reference standard for microwave power. *Natl. Inst. Stand. Technol. Tech. Note* 1357; 1993 April. 46p.
- [6] Clague, F.R. 7 mm coaxial microwave microcalorimeter. *Natl. Inst. Stand. Technol. Tech. Note* 1358; 1993 August. 46p.
- [7] Larsen, N.T. A new self-balancing dc-substitution rf power meter. *IEEE Trans. Instrum. Meas.* IM-25: 343-347; 1976 December.
- [8] Engen, G.F. A bolometer mount efficiency measurement technique. *J. Res. Nat. Bur. Stand. (U.S.)*. 65C(2): 113-124; 1961 April-June.
- [9] Larsen, N.T. 50 microdegree temperature controller. *Rev. Sci. Instrum.* 39(1): 1-12; 1968 January.
- [10] Harvey, M.E. Precision temperature-controlled water bath. *Rev. Sci. Instrum.* 39(1): 13-18; 1968 January.
- [11] Engen, G.F. A dc-rf substitution error in dual-element bolometer mounts. *IEEE Trans. Instrum. Meas.* IM-13: 58-64; 1964 June-Sept.
- [12] Crawford, M.L.; Koepke, G.H. Design, evaluation, and use of a reverberation chamber for performing electromagnetic susceptibility/vulnerability measurements. *Nat. Bur. Stand. (U.S.) Tech. note* 1092; 1986 April. 146 p.
- [13] Taylor, B.N.; Kuyatt, C.E. Guidelines for evaluating and expressing the uncertainty of NIST measurement results. *Natl. Inst. Stand. Technol. Tech. Note* 1297; 1993 January. 15 p.
- [14] American National Standard Definitions, Symbols, Formulas and Tables for Control Charts, ANSI/ASQC A1-1987, available from the American Society for Quality Control, 310 West Wisconsin Ave, Milwaukee, WI 53203.
- [15] Montgomery, Douglas C., *Introduction to Statistical Quality Control*, Second Edition, John Wiley and Sons, New York, NY, 1991.

## APPENDIX A. Measured Adapter Loss

Chapter 6 describes the determination of the calorimetric equivalence correction factor  $g$  for the microcalorimeter. The procedure uses a special type N male-to male adapter (made in the same way and of the same material as the reference standard bolometer mount) that connects two thermopile assemblies. The analysis requires a knowledge of the adapter loss (which is small). This appendix derives an expression for the loss in terms of the measurable S parameters.

The adapter is gold plated with an electroformed copper outer conductor and a beryllium copper inner conductor supported by a pair of dielectric beads. Figure A.1 is a cross section view of the adapter. The connector on the bottom is a type N male while the top connector is a type N male modified to allow mating with the APC-7 connector on the top thermopile (see figure 6.2).

The desired result is the ratio of the total power dissipated in the adapter to the net power entering the adapter. The adapter is a 2-port junction as shown in figure A.2. The input incident and reflected powers at port 1 are  $P_{i1}$  and  $P_{r1}$ , the output incident and reflected powers at port 2 are  $P_{i2}$  and  $P_{r2}$ . The net input power  $P_1$  at port 1 is

$$P_1 = P_{i1} - P_{r1}, \quad (\text{A-1})$$

and the net output power  $P_2$  at port 2 is

$$P_2 = P_{i2} - P_{r2}. \quad (\text{A-2})$$

The total power,  $P_D$ , dissipated in the adapter is given by the change in the incident power plus the change in the reflected power

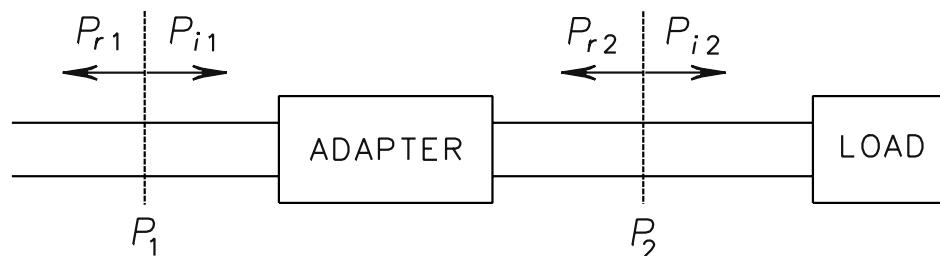


Figure A.1. Adapter cross section.

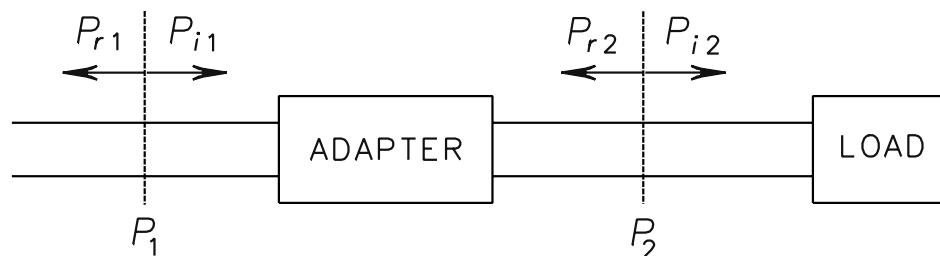


Figure A.2. The adapter as a 2-port junction.

$$P_D = (P_{i1} - P_{i2}) + (P_{r2} - P_{r1}). \quad (\text{A-3})$$

Rearranging terms gives

$$P_D = (P_{i1} - P_{r1}) - (P_{i2} - P_{r2}), \quad (\text{A-4})$$

which by eqs (A-1) and (A-2) is just the difference  $\mathbf{P}_1 - \mathbf{P}_2$  in the net powers.

The desired fractional loss then is given by

$$\frac{P_D}{P_1} = \frac{P_1 - P_2}{P_1} = 1 - \frac{P_2}{P_1}. \quad (\text{A-5})$$

The ratio of  $P_2$  to  $P_1$  is defined as the efficiency  $\eta_1$  of the junction when energy is fed into port 1. Assuming unit normalization, it is given by reference [A1]

$$\eta_1 = \frac{|S_{21}|^2 (1 - |\Gamma_L|^2)}{|1 - S_{22}\Gamma_L|^2 - |(S_{12}S_{21} - S_{11}S_{22})\Gamma_L + S_{11}|^2}. \quad (\text{A-6})$$

The S parameters are those of the adapter, and  $\Gamma_L$  is the reflection coefficient of the terminating load. If both  $\Gamma_L$  and  $S_{11}$  are sufficiently small,  $\eta_1$  reduces to

$$\eta_1 \approx |S_{21}|^2, \quad (\text{A-7})$$

and eq (A-5) becomes simply

$$\frac{P_D}{P_1} \approx 1 - |S_{21}|^2. \quad (\text{A-8})$$

The S parameters of the adapter and  $\Gamma_L$  of the terminating load were measured using the NIST 6-port network analyzer, and the efficiency calculated. The result is shown in figure A.3. The curve labeled "exact" was obtained using eq (A-6) and the curve labeled "approximate" using eq (A-7). The differences are small, with the largest at 7 and 18 GHz. A change of just  $2^\circ$  in the phase of  $\Gamma_L$  (using eq (A-6)) eliminates the difference at either frequency. Because the amplitude of  $\Gamma_L$  is small, the uncertainty in the phase measurement is  $20^\circ$ . The "approximate" values are adequate in this case, and eq (A-8) is used as the expression for the adapter loss.

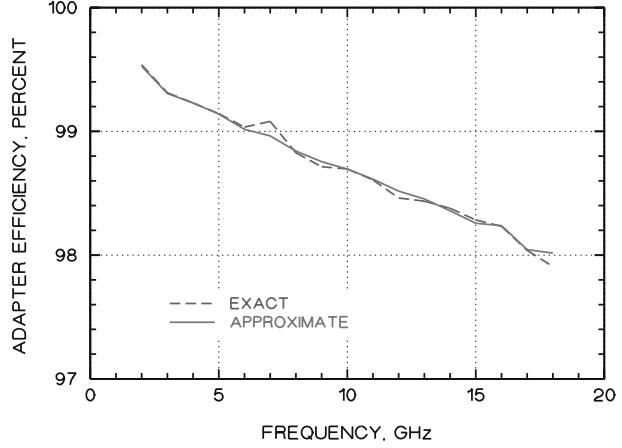


Figure A.3. Adapter efficiency.

## References

- [A1] Kerns, D.M.; Beatty, R.W. Basic theory of waveguide junctions and introductory microwave network analysis. New York: Pergamon Press Inc; 1967. 141 p.

## APPENDIX B. Theoretical Adapter Loss

Appendix A derives an expression for the loss of a special type N male-to-male adapter used in the determination of a correction factor  $g$  for the microcalorimeter. The result is in terms of measurable S parameters. The accuracy with which a small loss can be measured is limited at best, so additional support for the measurement in the form of a calculated result is useful.

The adapter is gold plated with an electroformed copper outer conductor and a beryllium copper inner conductor supported by a pair of dielectric beads. A cross sectional view of the adapter is shown in appendix A as figure A.1.

Calculation of the conductor loss for a plated coaxial transmission line is based on theory found in reference [B1]. Table 8.09 in the reference gives the attenuation due to the conductor as

$$\alpha_c = \frac{R}{2Z_0}, \quad (\text{B-1})$$

where  $R$  is the conductor resistance and  $Z_0$  is the transmission line characteristic impedance.  $R$  can be written in terms of the skin effect surface resistivity  $R_s$  as

$$R = \frac{R_s}{2\pi} \left( \frac{1}{a} + \frac{1}{b} \right). \quad (\text{B-2})$$

The radius of the inner conductor is  $a$  and the inner radius of the outer conductor is  $b$ . The surface resistivity is given by

$$R_s = \frac{1}{\sigma \delta}, \quad (\text{B-3})$$

where  $\sigma$  is the conductivity of the conductor and  $\delta$  is the skin depth. The skin depth is

$$\delta = \frac{1}{\sqrt{\pi f \mu \sigma}}, \quad (\text{B-4})$$

---

where  $f$  is the frequency and  $\mu$  is the conductor permeability.

The conductors, being gold plated, are actually made up of two layers. Layer 1 is gold and layer 2 is beryllium copper for the inner conductor and copper for the outer conductor. Using the results found in section 5.19 of reference [B1] for two-layer conductors, the expression for the equivalent surface resistivity  $R_s$  of the combination for either the inner or outer conductor is

$$R_s = \Re \left( R_{s1} (1 + j) \left[ \frac{\sinh \tau_1 d + (R_{s2}/R_{s1}) \cosh \tau_1 d}{\cosh \tau_1 d + (R_{s2}/R_{s1}) \sinh \tau_1 d} \right] \right). \quad (\text{B-5})$$

The subscripts 1 and 2 refer to the layers,  $d$  is the thickness of layer 1,

$$\tau_1 = \frac{(1 + j)}{\delta_1} = (1 + j) \sqrt{\pi f \mu_1 \sigma_1}, \quad (\text{B-6})$$

$$R_{S1} = \sqrt{\frac{\pi f \mu_1}{\sigma_1}}, \quad (\text{B-7})$$

and

$$R_{S2} = \sqrt{\frac{\pi f \mu_2}{\sigma_2}}. \quad (\text{B-8})$$

Finally then, the total coaxial line conductor loss  $A_C$  (in dB) is

$$A_C = 20 \ln \frac{L}{4 \pi Z_0} \left( \frac{R_{Si}}{a} + \frac{R_{So}}{b} \right), \quad (\text{B-9})$$

where  $L$  is the total line length, and  $R_{Si}$  and  $R_{So}$  are the results of applying eq (B-5) to the inner and outer conductors, respectively.

The loss due to joints at the connector and at the center conductor support beads is calculated using the experimental results found in reference [B2]. (Loss in the dielectric of the center conductor support bead is not included.) A general expression for the joint loss in dB is

$$A_J = A_0 + B f^E, \quad (\text{B-10})$$

where  $f$  is the frequency in GHz,  $A_0$  and  $B$  are small experimentally determined constants ( $\approx 0.01$ ), and  $E$  is a constant with a value between 0.5 and 1. The work reported in reference [B2] gives  $A_0$  a value of 0,  $B$  a value of 0.0088 for the type N joint and 0.0047 for a center conductor support bead joint, and  $E$  as 0.5 in both cases. Another investigator has found  $A_0$  to be approximately 0.005,  $C$  approximately 0.007, and  $E$  very likely somewhat larger than 0.5.

Figure B.1 shows the calculated curves for the conductor ( $A_C$ ), joint ( $A_J$ ), and total adapter loss as a function of frequency. Table B.1 gives the values chosen for the different parameters used in the calculations.

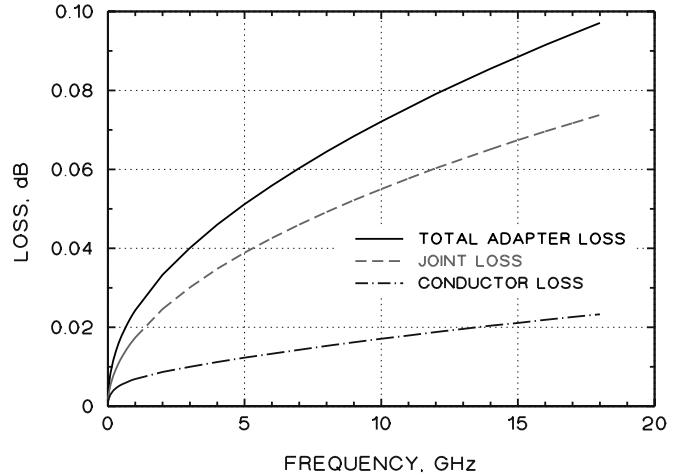


Figure B.1. Calculated adapter loss.

Table B.1. Values used in calculating adapter loss.

Fixed for all calculations:						
Parameter	Line length $L$ cm	Layer 1 (Au) permeability $\mu_1$ H/m	Layer 2 (Cu) permeability $\mu_2$ H/m	Inner cond. radius $a$ cm	Outer cond. radius $b$ cm	
Values	4.57	$4\pi \times 10^{-7}$	$4\pi \times 10^{-7}$	0.1521	0.3500	
Changed in different calculations:						
Parameter	Layer 1 (Au) thickness $d$ $\mu\text{m}$	Layer 1 (Au) conductivity $\sigma_1$ S/m	Layer 2 (Cu) conductivity $\sigma_2$ S/m	Joint loss factors		
Inner conductor loss calculation	1.27	$4.61 \times 10^7$	$8.00 \times 10^6$	—	—	—
Outer conductor loss calculation	1.27	$4.61 \times 10^7$	$5.75 \times 10^7$	—	—	—
Type N joint loss calculation	—	—	—	0	0.008	0.5
Bead joint loss calculation	—	—	—	0	0.0047	0.5

## REFERENCES

- [B1] Ramo, S.; Whinnery, J.R.; Van Duzer, T. Fields and waves in communication electronics. New York: John Wiley and Sons; 1965. 754 p.
- [B2] Daywitt, W.C. A simple technique for determining joint losses on a coaxial line from swept-frequency reflection data. IEEE Trans. Instrum. Meas. IM-36: 468-473; 1987 June.

## APPENDIX C. Thermopile Stability Testing

This appendix describes statistical methods and algorithms for detecting "stable" periods in thermopile voltages as they evolve in time. The statistical methods that have been used essentially search for two types of instability: nonrandomness and trend. None of the statistical methods makes assumptions about the particular distributional properties of the data. Since they are not linked to variability, the methods should not have the shortcomings of variance-based criteria that cannot be successfully tuned to handle unpredictable changes in variability that may occur in the system. The methods that have been implemented are discussed briefly below.

### RUNS TEST

A sequence of voltage readings  $\{v_1, v_2, \dots, v_n\}$  may be analyzed for randomness by considering the magnitude of each element relative to that of the immediately preceding element in the time sequence. If the next element is larger, a run up is started; if smaller, a run down. We observe when the sequence increases, and for how long, when it decreases, and for how long. A decision concerning randomness is then based on the number of runs,  $R$ . Long runs, leading to a small value of  $R$ , should not occur in a set of stable, random voltage readings. A runs analysis should be sensitive to either trends or other low frequency periodicities in the data.

The runs test calculation is a simple function of the difference sequence  $d_j = v_{j+1} - v_j$ , for  $j = 1, \dots, n - 1$ . Under the assumption of randomness, the expected number of runs,  $\mu_R$ , and the standard deviation,  $\sigma_R$ , of the number of runs for a sequence of length  $n$  are

$$\mu_R = \frac{2n - 1}{3}, \quad (C-1)$$

$$\sigma_R = \sqrt{\frac{16n - 29}{90}}. \quad (C-2)$$

If, for a given sequence of readings,  $R$  denotes the observed number of runs, the quantity

$$Z_R = \frac{R - \mu_R}{\sigma_R} \quad (C-3)$$

is used to test for nonrandomness. If the acceptable number of stable readings is  $n$ , then the value  $Z_R$  is calculated sequentially after each new voltage reading starting with the  $n$ th value obtained

after a change of frequency. Successive values of  $Z_R$  each are based on the preceding  $n$  readings, ending with the latest value. A threshold (or critical value) of  $Z_R$ , denoted by  $R_{CV}$ , determines if  $Z_R$  passes the test for stability based on the runs analysis. The criterion for RUNS stability is that  $Z_R \geq R_{CV}$  be satisfied. The particular value  $R_{CV}$  may be chosen to provide any desired sensitivity to detecting excessively long runs. Currently, the value  $R_{CV} = -2.5$  is being used.

### KENDALL'S TEST FOR TREND

The following test is useful to detect a particular type of nonrandomness: namely, a monotonic trend in the sequence  $\{v_1, v_2, \dots, v_n\}$ . The procedure is complementary to the runs test. It seems to be more sensitive to the types of voltage drifts seen in the system, probably because it considers the relative magnitude of each voltage reading relative to every preceding measurement.

Kendall's test is derived from

$$\tau = \frac{S}{\sqrt{D n(n-1)/2}}, \quad (\text{C-4})$$

where

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^n \text{sign} (v_j - v_i), \quad (\text{C-5})$$

$$D = \sum_{i=1}^{n-1} \sum_{j=i+1}^n [\text{sign} (v_j - v_i)]^2, \quad (\text{C-6})$$

and  $\text{sign}(d)$  is simply the sign of the voltage difference, or 0 if  $v_i = v_j$ . The value of  $\tau$  is a measure of association between the voltage sequence and "time," and hence is indicative of trend. Its interpretation is similar to the usual correlation coefficient, for instance, it takes values between -1 and 1.

To use Kendall's test for trend, we compute the test statistic

$$Z_S = \frac{S}{\sqrt{\text{Var}(S)}}, \quad (\text{C-7})$$

where

$$\text{Var}(S) = [n(n-1)(2n+5) - T_v] / 18, \quad (\text{C-8})$$

and  $T_v = 0$  if there are no common voltages (i.e., ties) in the data sequence. Otherwise,  $T_v$  is computed by sorting the sequence and computing the multiplicity of each group of tied values. Then,

$$T_v = \sum t(t-1)(2t+5), \quad (C-9)$$

where the summation is over the number of sets of tied values. For a given set,  $t$  is the corresponding number of tied values ( $t \geq 2$ ).

The software computes a probability ( $p$ ) associated with  $Z_S$ , where a small value (say  $p < 0.25$ ) would show an increasing trend and a large value (say  $p > 0.75$ ) shows a significant decreasing trend. The particular values used to compare to  $p$  are arbitrary tuning constants that have been set by experience with the algorithm on the system. As the algorithm is refined and tested, the particular values of the tuning constants may be revised. Currently, the TREND criterion for accepting a sequence of  $n$  voltage readings as stable is that  $0.25 < p < 0.75$ .

### STABILITY ALGORITHM

Suppose that  $n_a$  successive voltage readings are required for stability. Let  $\mu_R$  and  $\sigma_R$  be the expected runs and standard deviation in equations (C-1) and (C-2) for sample size  $n_a$ . Following a change of frequency the algorithm is entered with an initial data set  $\{v_1, v_2, \dots, v_n\}$  such that  $n \geq n_a$ .

- (A)  $j \leftarrow n - n_a + 1$ ; Data =  $\{v_j, v_{j+1}, \dots, v_n\}$
- (B) Compute:  $R, Z_R; S, Z_S, p$  from  $n_a$  readings in Data.
- (C) If  $(Z_R \geq -2.5)$  and  $(0.25 < p < 0.75)$  then: compute  $\bar{v} = \text{Average (Data)}$ ;  $S_V = \text{Standard Deviation (Data)}$ ; EXIT: Data is stable. Otherwise, GOTO (D).
- (D)  $n \leftarrow n + 1$ ;  $v_n \leftarrow \{\text{next voltage}\}$ ; GOTO (A).

## EXAMPLES

Figure C.1 shows the thermopile output for measurements at five frequencies on mount CN27\_04. Graphical illustrations of the stability testing results at the first three frequencies are shown in figures C.2 - C.4. In each of the three figures, the vertical dashed lines represent endpoints of the region found to be acceptably stable, while the horizontal dashed line is plotted at the average voltage of readings in the stable region.

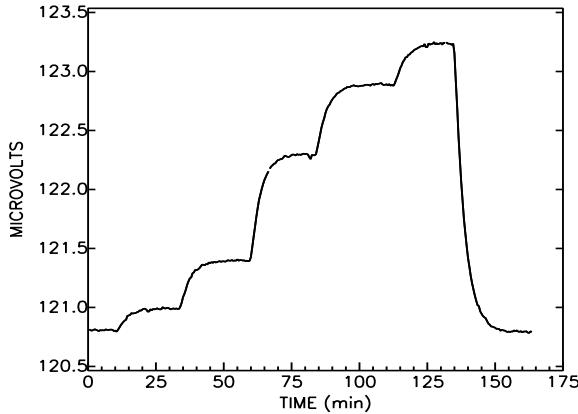


Figure C.1. Thermopile output versus time for CN27 at five check frequencies.

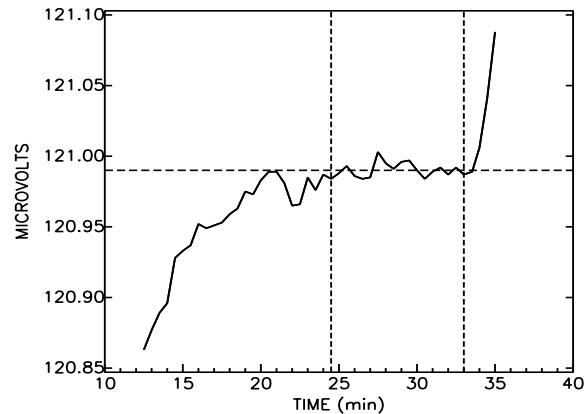


Figure C.2. Thermopile output versus time for CN27 at 100 MHz.

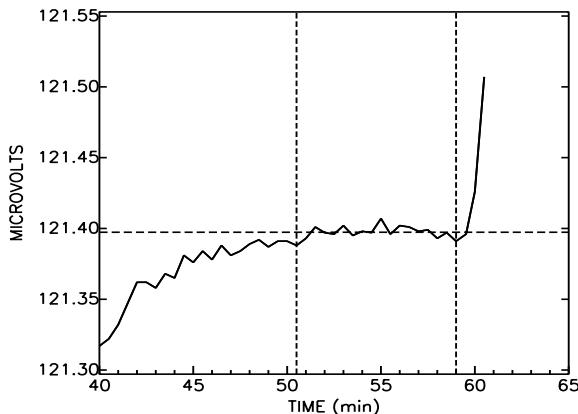


Figure C.3. Thermopile output versus time for CN27 at 3 GHz.

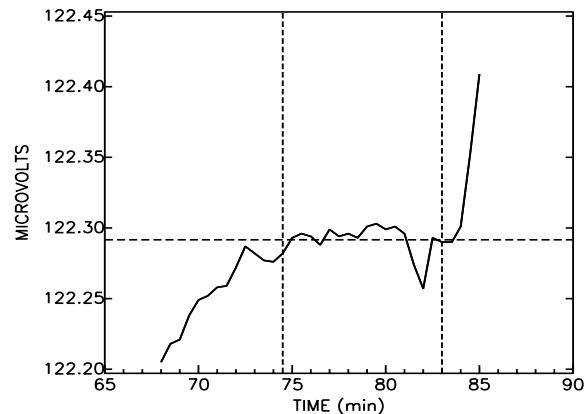


Figure C.4. Thermopile output versus time for CN27 at 10 GHz.

To illustrate the calculations, the sequence of numerical results at 10 GHz are listed in Tables C.1 and C.2. Since the required number of stable readings was  $n_a = 18$ , Table C.1 simply shows the sequential average and standard deviation calculated after each of the initial 17 readings. Stability checking (see Table C.2) began after the 18th reading, with the initial test results  $Z_R = -6.29$  and  $Z_S = 5.80$  with  $p = 0.00$ . The entries following  $Z_R$  and  $p$  show the respective test conclusions, indicating if the prior 18 readings passed (P) or failed (F) the RUNS and TREND stability tests, respectively, based on the criteria at step (C) of the algorithm. As the table shows, both procedures successfully passed tests after the 47th reading, thereby indicating that  $\{v_{30}, v_{31}, \dots, v_{47}\}$  was an acceptable data set. The resulting average,  $\bar{v} = 122.2916 \mu\text{V}$ , was used in calculating the effective efficiency at 10 GHz.

Table C.1. Initial readings for mount CN27\_04 at 10 GHz.

<b><i>n</i></b>	Time,s	$\mu\text{V}$	Average	S.D.
1	3600.1	121.426	121.4260	0.0000
2	3630.1	121.507	121.4665	0.0573
3	3660.1	121.598	121.5103	0.0860
4	3690.1	121.679	121.5525	0.1098
5	3720.1	121.764	121.5948	0.1341
6	3750.1	121.839	121.6355	0.1560
7	3780.1	121.912	121.6750	0.1766
8	3810.1	121.957	121.7103	0.1915
9	3840.1	122.004	121.7429	0.2042
10	3870.1	122.046	121.7732	0.2150
11	3900.1	122.081	121.8012	0.2241
12	3930.1	122.107	121.8267	0.2312
13	3960.1	122.132	121.8502	0.2370
14	3990.1	122.153	121.8718	0.2417
15	4020.1	122.177	121.8921	0.2458
16	4050.1	122.196	121.9111	0.2494
17	4080.1	122.205	121.9284	0.2517

Table C.2. Stability checking at 10 GHz: Average and S.D. of last 18 readings.

<b><i>n</i></b>	Time, s	μV	Average	S.D.	<b><i>Z<sub>R</sub></i></b>	<b><i>Z<sub>S</sub></i></b>	<b><i>p</i></b>
18	4110.1	122.218	121.9445	0.2536	-6.29 F	5.80	0.00 F
19	4140.1	122.221	121.9887	0.2257	-6.29 F	5.80	0.00 F
20	4170.1	122.238	122.0293	0.1980	-6.29 F	5.80	0.00 F
21	4200.1	122.249	122.0654	0.1723	-6.29 F	5.80	0.00 F
22	4230.1	122.252	122.0973	0.1480	-6.29 F	5.80	0.00 F
23	4260.1	122.258	122.1247	0.1268	-6.29 F	5.80	0.00 F
24	4290.1	122.259	122.1481	0.1084	-6.29 F	5.80	0.00 F
25	4320.1	122.272	122.1681	0.0947	-6.29 F	5.80	0.00 F
26	4350.1	122.287	122.1864	0.0826	-6.29 F	5.80	0.00 F
27	4380.1	122.282	122.2018	0.0717	-5.70 F	5.72	0.00 F
28	4410.1	122.277	122.2147	0.0623	-5.70 F	5.57	0.00 F
29	4440.1	122.276	122.2255	0.0541	-5.70 F	5.34	0.00 F
30	4470.1	122.282	122.2352	0.0467	-5.11 F	5.23	0.00 F
31	4500.1	122.293	122.2442	0.0409	-5.11 F	5.23	0.00 F
32	4530.1	122.296	122.2521	0.0357	-5.11 F	5.23	0.00 F
33	4560.1	122.294	122.2586	0.0316	-4.52 F	5.16	0.00 F
34	4590.1	122.288	122.2637	0.0281	-4.52 F	4.93	0.00 F
35	4620.1	122.299	122.2689	0.0251	-3.93 F	4.93	0.00 F
36	4650.1	122.294	122.2732	0.0223	-3.34 F	4.74	0.00 F
37	4680.1	122.296	122.2773	0.0187	-2.75 F	4.63	0.00 F
38	4710.1	122.293	122.2804	0.0162	-2.16 P	4.22	0.00 F
39	4740.1	122.301	122.2833	0.0149	-1.57 P	4.22	0.00 F
40	4770.1	122.303	122.2861	0.0134	-1.57 P	4.22	0.00 F
41	4800.1	122.299	122.2884	0.0117	-0.98 P	4.03	0.00 F
42	4830.1	122.301	122.2907	0.0094	-0.39 P	3.92	0.00 F
43	4860.1	122.296	122.2921	0.0083	-0.39 P	3.47	0.00 F
44	4890.1	122.274	122.2913	0.0092	-0.39 P	2.48	0.01 F
45	4920.1	122.257	122.2899	0.0121	-0.39 P	1.45	0.07 F
46	4950.1	122.293	122.2908	0.0117	-0.39 P	0.84	0.20 F
47	4980.1	122.290	122.2916	0.0111	0.20 P	0.00	0.50 P

## APPENDIX D. Software Listing

```

File$="MICRO_C5AP" ! Started:8610231615/FRC
Rev$="9200106144" ! FRC,BFR

!
! This program is a modification of MICRO.CAL. Its application is the
! effective efficiency measurement of a thermistor mount using the
! coax microcalorimeter. Default menu choices and the correction factor
! are set for coax waveguide microcalorimeter measurements can also
! be made by choosing the appropriate menu item and changing
! the correction factor. The correction factor is changed by changing
! the four lines labeled G, G1, G2, and G3, and the RF subprogram.
!
! Thermopile output (using the Kieftley 181 nanovoltmeter),
! and power meter voltages are the measured parameters.
!
! Provision for temperature measurement is made but not implemented in
! this version. It controls the instrumentation, does the calculations,
! and outputs the results.
!
! NOTES: This version can turn dc bias on & off, checking the
! nanovoltmeter and thermopile zero.
!
! This version is saving & looking for the temperature array, Tp,
! even though it is not measured.
!
! This version can run the entire frequency range of the coax
! mounts, automatically.
!
INSTRUMENTS CONTROLLED:
    1. HP345TA DVM
    2. HP3488A SWITCH CONTROL UNIT
    3. EIP 578 LOCKING COUNTER
    4. KEITHLEY 181 DIGITAL NANOVOLTMETER
    5. EIP 931 0.01 - 18.6 GHZ SOURCE
    6. DATA PRECISION 8200 DC SOURCE
!
DESCRIPTION OF THE MAIN VARIABLES:
These are in the labeled common /Data/.
!
* Dfile$ is the name of the data file (may include drive extension).
* File_id$ is the identifier of the mount calibrated.
290   ! File name code example:
291   !   9090060510
292   !   / \ /
293   !   Waveguide: WR-90   Date (year, mo, day, hour)
300   !   (Coax: Type N = cn, APC-7 = c7)
305   !
310   !   File1$ is the name of the program that generated the data file.
311   !   Mount_id$ is the identifier of the mount calibrated.
320   !   AF, an array containing in each row of three columns the Start,
325   !   Stop, and Step sequences for each measurement set.
330   !   The following are real arrays with TWO dimensions. -----
335   !   V, an array containing in Col 1: the time of measurement;
340   !   in Col 2: the measured power meter voltages;
345   !   E, an array containing in Col 1: the time of measurement;
350   !   in Col 2: the measured thermopile output voltage.
355   !   Ne, an array containing in each row of three columns the Start,
360   !   the effective efficiency.
365   !   F, an array containing in Col 1: the frequencies; in Col 2:
370   !   the beginning measurement No. for that frequency.
375   !   Ne, an array containing in Col 1: the frequency; in Col 2:
380   !   the effective efficiency.
385   !
390   !   The following is a real array with ONE dimension. -----
395   !   Header, an array with 27 elements, containing the housekeeping
400   !   information.
405   !   Each element is defined as follows:
410   !       (1) - Rev$, revision No., yr-no-day-hour-min-sec format.
415   !       (2) - Test date, in "Timedate" format.
420   !       (3) - Band Id, i.e. "90" for WR-90.
425   !       (4) - Efficiency Flag, indicates data set includes Ne,
!
        ! Started:8610231615/FRC,BFR
        ! Total number of measurement frequencies
        ! Starting measurement frequency
        ! Final measurement frequency
        ! Step frequency size (the first step may be different)
        ! Total No. of measurements
        ! Elapsed time for measurement series, sec
        ! Measurement interval, sec
        ! Nominal rf power level, mW
        ! Reference voltage, volts
        ! Mount operating resistance, ohms
        ! Nanovoltmeter zero correction, volts
        ! Pre-bias flag, mount dc biased before run
        ! Room temperature
        ! Bath temperature
        ! Zero correction flag, data includes dc OFF
        ! Auto measure flag, indicates full data set taken
        ! and stored automatically
        ! Random frequency order flag
!
        ! The following is an integer array with ONE dimension. -----
        ! * Tp, an array containing the temperature measurements.
        ! *****
        ! ***** INITIALIZATION *****
        ! OPTION BASE 1
        ! KEY LABELS OFF
        ! Default graphics parameters
        ! PLOTTER IS CRT, "INTERNAL";COLOR MAP
        ! Print color white
        !
        ! Common:
        ! Variables to put in common
        COM /Data/ Dfiles$[20],File1$[16] Mount_ids$[16]
        COM /Data/ V(3000,2),E(3000,2),F(500,2),Ne(100,2),Header$[27]
        COM /Data/ Af(10,3),INTEGER,Tcv,Rcv,Env,Sdrn,Volts(100),INTEGER Mode,Lss
        COM /Init_stats/Tcv,Rcv,Env,Sdrn,Volts(100),INTEGER Mode,Lss
        COM /Flogs/ Manual_freqs
        COM /XY_coordinates/ Timin,Timax,Vpmin,Vpmax
        !
        ! Mcontrol: ! *****
        ! Init time maximum, in seconds.
        620   Timax=4200
        625   Timin=0
        630   Vpmax=1.21E-4
        635   Vpmin=1.17E-4
        640   Lss=18
        645   !
        650   Mcontrol: ! *****
        ! MAIN MENU AND CONTROL *****
        655   IF V(1,2) OR E(1,2) THEN CALL New_size ! If data still in common, re_dim
        660   ! " minimum, "
        665   ! " maximum, "
        670   ! " minimum, in volts.
        675   ! " maximum, "
        680   ! " minimum, "
        685   Mcontrol: ! *****
        690   ON KEY N LABEL " GOTO Top
        695   IF V(1,2) OR E(1,2) THEN CALL New_size ! If data still in common, re_dim
        700   Sys_prt=VAL(SYSTEM$("SYSTEM_PRIORITY")) !Determine system priority
        705   Lcl_prt=Sys_prt+1 !Set local priority 1 higher for ON KEY
        710   ! Softkey interrupts:
        715   FOR N=0 TO 19
        720   ! ON KEY N LABEL " GOTO Top
        725   NEXT N
        730   ON KEY 0 LABEL " EXIT PROGRAM ",Lcl_prt GOTO End
        735   ON KEY 5 LABEL " SELECT (1) ",Lcl_prt GOSUB Measure
        740   ON KEY 6 LABEL " SELECT (2) ",Lcl_prt GOSUB Calcdisp
        745   ON KEY 7 LABEL " SELECT (3) ",Lcl_prt GOSUB Loadfile
        750   ON KEY 9,Lcl_prt CALL Blank !Turn CRT back on after meas
        755   M_flg=1
        760   KEY LABELS ON
        765   Top:LOOP
!
```

```

775 IF M_flg THEN GOSUB Main_menu
776 END LOOP
780 !
785 Measure:
    !Local integer variables
    !Initialize the software
    !Put program file name into common
    !Put program revision # in
    !Put Mount_id$ into Mount_id
    !To get the mount identifier
    !Initialize the hardware
    !Start a counter for loop
820 Counter=0
825 Mkl:
830 LOOP
835 EXIT IF Nomore_f
840 Counter=Counter+1
845 IF Counter=1 THEN
    CALL Generate_freq(Nomore_f,Counter) !Produces start, stop, step freq
850 CALL Freq_change_pts(1) !Set up frequency list & display
855 CALL New_size !Resize after any possible changes
860 CALL Display_data !Init the voltage/time parameters
865 ELSE !After the first time
870 CALL Re_set !Partial software init
875 CALL Generate_freq(Nomore_f,Counter) !Produces start, stop, step freq
880 CALL New_size !Resize arrays
885 CALL Freq_change_pts(0) !Set up frequency list, no display
890 END IF
895 IF Counter=1 AND Header(16) THEN CALL Pre_bias(1) !To set up for
900 pre_bias
905 IF Counter=1 THEN CALL Delay_start !Wait until start time
910 IF Counter=1 AND Header(16) THEN CALL Pre_bias(0) !To do the pre_bias
915 CALL File_name !To set up the file name
920 CALL Meas_disp !To set up screen display for Meas
925 IF NOT Header(19) THEN CALL DC(1,2) !Be sure bias is on, if no zero
check
930 CALL Meas !Do the measurement
935 IF Header(20) THEN CALL Save_data(1) !If auto mode, save the meas
940 EXIT IF NOT Header(20) !Once thru if manual or bail out
945 END LOOP
950 M_flg=1
955 RETURN
960 !
965 Calcdisp:
970 IF V(1,2) OR E(1,2) THEN
    CALL Calc_disp
975 M_flg=1
    !Check for data in the memory
980 CALL Flash(" NO DATA IN MEMORY ")
985 M_flg=1
    !To restore menu
990 CALL Flash(" NO DATA IN MEMORY ")
995 M_flg=1
    !Because no data in memory
1000 END IF
1005 RETURN
1010 !
1015 Iodile:
1020 CALL Io_dfile
1025 M_flg=1
    !To restore menu
1030 RETURN
1035 !
1040 Main_menu:
1045 OUTPUT KBD;"K";
1050 PRINT TABXY(5,12),CHR$(137)&"M I C R O - C x A P"&CHR$(136)
Crt_ids=SYSTEMS("CRT ID")
1055 IF Crt_ids[4,5]="80" THEN
1060 CLIP 10,117,24,84
1065 ELSE
1070 CLIP 4,74,62,92
1080 END IF
1085 PEN 5
1090 FRAME
1095 PRINT TABXY(25,7)," - - - - - MAIN MENU - - - - -"

```

---

```

1100 PRINT TABXY(25,10)," (1) MEASURE EFFICIENCY"
1105 PRINT TABXY(25,12)," (2) CALCULATE & DISPLAY RESULTS"
1110 PRINT TABXY(25,14)," (3) DATA FILE I/O"
1115 IF V(1,2) OR E(1,2) THEN
1120 PRINT TABXY(59,18),CHR$(129)&" DATA IN MEMORY "&CHR$(128)
1125 IF Dfile$="" THEN
1130 PRINT TABXY(59,19),CHR$(129)&" (NO FILE NAME)"&CHR$(128)
1135 ELSE
1140 PRINT TABXY(59,19),CHR$(129)&" FILE:"&file$&CHR$(128)
1145 END IF
1150 PRINT TABXY(56,19),CHR$(129)&" NO DATA IN MEMORY "&CHR$(128)
1155 END IF
1160 END IF
1165 M_flg=0
1170 RETURN
1175 !
1180 End:CLEAR SCREEN
1185 END! MICRO-CX??
1190 ! * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
1195 Io_dfile:
SUB Io_dfile
OPTION BASE 1
1200 COM /Data/ Dfile$[20],File1$[16],Mount_id$[16]
1210 COM /Data/ V(3000,2),E(3000,2),F(500,2),Ne(100,2),Header(27)
1220 COM /Data/ Af(10,3),INTEGER TP(3000)
1225 M_flg=1
1230 No=Header(9)
1235 Sys_prtv=SYSYSTEMS("SYSTEM PRIORITY") !Total measurement #
1240 Lcl_prtv=Sys_prtv+1
1245 FOR N=0 TO 19 !Set local priority 1 higher for ON KEY
    ON KEY N LABEL " GOTO Top
1250 NEXT N
1255 ON KEY 0 LABEL " MAIN MENU ",Lcl_prtv GOTO Exit
1260 ON KEY 5 LABEL " SELECT (1) ",Lcl_prtv GOSUB DispHdr
1265 ON KEY 6 LABEL " SELECT (2) ",Lcl_prtv GOSUB Get_data
1270 ON KEY 7 LABEL " SELECT (3) ",Lcl_prtv GOSUB Save_data
1275 ON KEY 8 LABEL " "
1280 KEY LABELS ON
1285 Top:LOOP
1290 IF M_flg THEN GOSUB Menu
1295 END LOOP
1300 !
1305 DispHdr:
    IF Header(1) THEN
        CALL Disp_hdr
    ELSE
        M_flg=1
    END IF
1310 !Check for header data
1315 CALL Disp_hdr
1320 M_flg=1
    !Check for data in the memory
1325 ELSE
    M_flg=1
    !To restore menu
1330 CALL Flash(" NO HEADER DATA IN MEMORY ")
    !Because no data in memory
1335 M_flg=1
1340 END IF
1345 RETURN
1350 !
1355 Save_data:
    IF V(1,2) OR E(1,2) THEN
        !Check for data in the memory
        !Not an auto mode save
    ELSE
        M_flg=1
        !To restore menu
    END IF
1360 CALL Save_data(0)
1365 !
1370 M_flg=1
    !Because no data in memory
1375 CALL Flash(" NO DATA IN MEMORY ")
    !Retieve BDAT data file
1380 M_flg=1
1390 END IF
1395 RETURN
1400 !
1405 Get_data:
    CALL Get_data
1410 M_flg=1
1415 !
1420 RETURN
1425 !
1430 Menu:

```

```

1435 OUTPUT KBD;"K"; !Clear screen
1440 PRINT TABXY(5,2),CHR$(137)&"M I C R O - C x A P"&CHR$(138)
1445 PEN 1
1450 FRAME
1455 PRINT CHR$(138)
1460 PRINT TABXY(25,7),"-- DATA I/O MENU -- -- "
1465 PRINT TABXY(25,10)," (1) Head listing change"
1470 PRINT TABXY(25,12)," (2) Input a data file"
1475 PRINT TABXY(25,14)," (3) Output a data file"
1480 IF V(1,2) OR E(1,2) THEN
1485 PRINT TABXY(59,18),CHR$(129)&" DATA IN MEMORY "&CHR$(128)
1490 IF Dfile$="" THEN
1495 PRINT TABXY(59,19),CHR$(129)&" (NO FILE NAME)"&CHR$(128)
1500 ELSE
1505 PRINT TABXY(59,19),CHR$(129)&" FILE:&Dfile$&CHR$(128)
1510 END IF
1515 ELSE
1520 PRINT TABXY(56,19),CHR$(129)&" NO DATA IN MEMORY "&CHR$(128)
1525 END IF
1530 M_flag=0
1535 RETURN
1540 !
1545 Exit:OFF KEY
1550 SUBEND ! Io_dfile
1555 ! * * * * * * * * * * * * * * * * * * * * * * * *
1560 Disp_hdr: !
1565 SUB Disp_hdr
1570 OPTION BASE 1
1575 COM /Data/ Dfiles[20],File$[16] Mount_ids[16]
1580 COM /Data/ V(3000,2),F(3000,2),F(500,2),Ne(100,2),Header(27)
1585 COM /Data/ Ar(10,3),INTEGER Tp(3000)
1590 INTEGER Ans
1595 Disp_hdr: !Print out the header items
1600 OUTPUT KBD;"K";
1605 IF V(1,1) THEN
1610 PRINT TABXY(17,1),CHR$(138);CHR$(132);!"HEADER LISTING"
1615 FOR :"&CHR$(128);CHR$(136);"
1620 ELSE
1625 PRINT TABXY(17,1),CHR$(138);CHR$(132);!"HEADER LISTING"
1630 FOR :"&CHR$(128);CHR$(136);"
1635 PRINT "Option Array #"
1640 PRINT "(1) -- -- Data file name: "&CHR$(136);Dfile$;CHR$(138)
1645 PRINT "(2) -- -- Mount ID: "&CHR$(136);Mount_ids;CHR$(138)
1650 PRINT "(3) -- -- Measurement program:
1655 :&CHR$(136);File$;CHR$(138)
1660 IMAGE "(4) [1] Revision #: "A_ZZZZZZZZZZ,A
1665 PRINT USING 1655;CHR$(136);Header(1);CHR$(138)
1670 IF Header<(2) THEN
1675 PRINT "(5) [2] Test date: "&CHR$(136);DATE$(Header(2));",
1680 PRINT "(6) [3] Band ID: WR-";CHR$(136);Header(3);CHR$(138)
1685 END IF
1690 IF Header<(3) THEN
1695 PRINT "(6) [3] Band ID: WR-";CHR$(136);Header(3);CHR$(138)
1700 ELSE
1705 PRINT "(6) [3] Band ID: "CHR$(136);"Coax";CHR$(138)
1710 END IF
1715 PRINT "(7) [4] Effective efficiency flag:
1720 PRINT "(8) [5] No. of measurement frequencies:
1725 PRINT "(9) [6] Start frequency:
1730 PRINT "(10) [7] Stop frequency:
1735 ;CHR$(136);Header(7);CHR$(138);"
1740 PRINT "(12) [9] Number of measurements:
1745 PRINT "(13) [10] Measurement duration: "A_ZZ_DD_A," hr"
1750 PRINT "(14) [11] Measurement interval:
1755 IMAGE "(15) [12] Nominal power: "A_DD_D_A," mW"
1760 PRINT "(16) [13] Voltage reference:
1770 PRINT "(17) [14] Mount operating resistance:
1775 PRINT "(18) [15] Nanovoltmeter zero correction:
1780 PRINT "(19) [16] Mount pre_bias flag:
1785 PRINT "(20) [17] Room temperature:
1790 PRINT "(21) [18] Bath temperature:
1795 PRINT "(22) [19] Zero correction flag:
1800 PRINT "(23) [20] Auto meas flag:
1805 PRINT "(24) [21] Random freq order flag:
1810 PRINT "(25) [22] Random freq order flag:
1815 PRINT CHR$(136);Header(18);CHR$(138)
1820 CONTROL CRT,12:2 !Turn on key labels
1825 Sys_Prtv=VAL(SYSTEM$("SYSTEM_PRIORITY")) !Determine system priority
1830 Lcl_Prtv=sys_prtv+1 !Set local priority 1 higher for ON KEY
1835 FOR N=0 TO 19
1840 ON KEY N LABEL "" GOTO Top
1845 NEXT N
1850 ON KEY 5 LABEL "CHANGE LISTING",Lcl_Prtv GOTO Edit
1855 ON KEY 0 LABEL "CONTINUE",Lcl_Prtv GOTO Disp_exit
1860 Top:LOOP
1865 END LOOP
1870 Edit: !
1875 CONTROL CRT,12:1 !Turn off labels
1880 INPUT "Input item number to change: ",Ans
1885 SELECT Ans
1890 CASE 1
1895 INPUT "Input new data file name: ",Dfile$
1900 CASE 2
1905 INPUT "Input mount ID: ",Mount_ids
1910 CASE 3
1915 INPUT "Input measurement program name: ",File1$ 
1920 CASE 4
1925 INPUT "Input revision number: ",Header(1)
1930 CASE 5
1935 GOTO Disp_hdr
1940 CASE 6
1945 INPUT "Input band ID: ",Header(3)
1950 CASE 7
1955 INPUT "Effective efficiency flag: ",Header(4)
1960 CASE 8
1965 INPUT "No. of measurement frequencies: ",Header(5)
1970 CASE 9
1975 INPUT "Input start frequency: ",Header(6)
1980 CASE 10
1985 INPUT "Input stop frequency: ",Header(7)
1990 CASE 11
1995 INPUT "Input step frequency: ",Header(8)
2000 CASE 12
2005 INPUT "Input no. of measurements: ",Header(9)
2010 CALL New_size

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2015 CASE 14 "Input measurement interval:",Header(11) !To graph thermopile
2020 CASE 15 "Input power:" ,Header(12)
2025 CASE 16 "Input zero correction:" ,Header(13)
2030 CASE 17 "Mount pre-bias flag:" ,Header(14)
2035 GOTO Disp_hdr
2040
2045 INPUT "Input mount resistance:" ,Header(14)
2050 CASE 18 "Nanovoltmeter zero correction:" ,Header(15)
2055 INPUT "Mount temperature:" ,Header(16)
2060 CASE 19 "Mount pre-bias flag:" ,Header(17)
2065 INPUT "Room temperature:" ,Header(18)
2070 CASE 20 "Auto meas flag:" ,Header(19)
2075 INPUT "Random freq order flag:" ,Header(20)
2080 CASE 21 "Bath temperature:" ,Header(18)
2085 CASE 22 "Zero correction flag:" ,Header(19)
2090 CASE 23 "Auto meas flag:" ,Header(17)
2095 INPUT "Mount temperature:" ,Header(15)
2100 CASE ELSE GOTO Disp_hdr
2105 END SELECT
2110 Disp_exit:
2115 GOTO Disp_hdr
2120 INPUT "OFF KEY"
2125 SUBND *****
2130 !* * * * * * * * * * * * * * * * * * * * * * * * * * * * *
2135 Calc_disp:
2140 GOTO Disp_hdr
2145 Disp_exit:
2150 OFF KEY
2155 SUBND *****
2160 !* * * * * * * * * * * * * * * * * * * * * * * * * * * * *
2165 Calc_disp:
2170 SUB Calc_disp
2175 OPTION BASE 1
2180 COM /Data/ Dfiles[20],File1$[16],Mount_ids$[16]
2185 COM /Data/ V(3000,2),E(3000,2),F(3000,2),Ne(100,2),Header(27)
2190 COM /Data/ Af(10,3),INTEGER,TP(3000)
2195 COM /Graph_prt/ Pwr(100,2) !Power array
2200 DIM B$(60)
2205 Sys_prtVAL(systems("SYSTEM PRIORITY")) !Determine system priority
2210 Lcl_prtSys_prt+1 !Set local priority 1 higher for ON KEY
2215 FOR N=0 TO 19
2220 ON KEY N LABEL " " GOTO Top
2225 NEXT N
2230 ON KEY 0 LABEL " MAIN MENU " Lcl_prt GOSUB Graph
2235 ON KEY 5 LABEL " SELECT (1) " Lcl_prt GOSUB Graph
2240 ON KEY 6 LABEL " SELECT (2) " Lcl_prt GOSUB Graph
2245 ON KEY 7 LABEL " SELECT (3) " Lcl_prt GOSUB Graph
2250 ON KEY 8 LABEL " SELECT (4) " Lcl_prt GOSUB Graph
2255 ON KEY 9 LABEL " SELECT (5) " Lcl_prt GOSUB Graph
2260 ON KEY 1 LABEL " SELECT (6) " Lcl_prt GOSUB Graph
2265 M_Flg=1 !Set flag to print menu
2270 Top:LOOP !Graphs power meter voltage output
2275 IF M_Flg THEN GOSUB Menu
2280 END LOOP
2285 Grphv:
2290 IF V(1,1)=0 THEN CALL Flash(" NO DATA ")
2295 ELSE Pflg=1
2300 BS="MOUNT VOLTAGE CHANGE VS TIME"
2305 CALL Graph_v(Pflg,B$)
2310 END IF
2315 M_Flg=1
2320 CALL Graph_v(Pflg,B$)
2325 END IF
2330 RETURN
2335 Grphv:
2340 !Graphs thermopile nanovolt output
2345 RETURN
2350 !Graphs temperature probe output
2355 Pltflg=2
2360 BS="THERMOPILE VOLTAGE CHANGE VS TIME"
2365 CALL Graph_v(Pltflg,B$)
2370 M_Flg=1 !To restore menu
2375 RETURN
2380 !
2385 Grphv:
2390 IF TP(1)=0 THEN CALL Flash(" NO DATA ")
2395 ELSE Pflg=3
2400 BS="TEMPERATURE CHANGE VS TIME"
2405 CALL Graph_v(Pltflg,B$)
2410 END IF
2415 M_Flg=1
2420 RETURN
2425 M_Flg=1
2430 RETURN
2435 !
2440 Grphv:
2445 OUTPUT KBD;"K";
2450 IF NOT Header(4) THEN CALL Eff_calc
2455 done
2455 Pflg=0
2460 CALL Graph_n_p(Pflg)
2465 M_Flg=1
2470 RETURN
2475 !
2480 Grphv:
2485 OUTPUT KBD;"K";
2490 IF NOT Pwr(1,1) THEN CALL Eff_calc
2495 CALL Graph_n_p(Pflg)
2500 M_Flg=1
2505 RETURN
2510 !
2515 !
2520 Calc_sd:
2525 OUTPUT KBD;"K";
2530 CALL StdDev
2535 M_Flg=1
2540 RETURN
2545 Menu:
2550 OUTPUT KBD;"K";
2555 PRINT TABXY(5,2),CHR$(137)&"M I C R O - C x A P"&CHR$(136)
2560 Crt_ids=SYSTEMS("CRT ID")
2565 IF Crt_ids[4,5]>"80" THEN
2570 CLIP 10,117,24,84
2575 ELSE
2580 CLIP 4,74,62,92
2585 END IF
2590 PEN 1
2595 FRAME
2600 PRINT CHR$(140)
2605 PRINT TABXY(20,6)," - - - - - CALCULATE DISPLAY MENU - - - "
2610 PRINT TABXY(25,8)," (1) Graph power meter voltage"
2615 PRINT TABXY(25,10)," (2) Graph thermopile voltage"
2620 PRINT TABXY(25,12)," (3) Graph Print effective efficiency"
2625 PRINT TABXY(25,14)," (4) Graph Rf Power"
2630 PRINT TABXY(25,16)," (5) Graph Temperature"
2635 PRINT TABXY(25,18)," (6) calculate standard deviation"
2640 IF V(1,2) OR E(1,2) THEN
2645 PRINT TABXY(59,18),CHR$(129)&" DATA IN MEMORY "&CHR$(128)
2650 IF Dfile$="" THEN
2655 PRINT TABXY(59,19),CHR$(129)&" (NO FILE NAME) "&Dfile$&CHR$(128)
2660 ELSE
2665 PRINT TABXY(59,19),CHR$(129)&" FILE:&Dfile$&CHR$(128)
2670 END IF
2675 ELSE
2680 PRINT TABXY(56,19),CHR$(129)&" NO DATA IN MEMORY "&CHR$(128)
2685 END IF

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2690 M_flg=0
2695 RETURN
2700 EXIT:OFF KEY
2705 SUBEND
2710 ! * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
2715 Graph_V:
2720 SUB Graph_V(Ptflg,B$) !Graphs voltage as a function of time
2725 ! For Ptflg=1 : Graph power meter voltage
2730 ! For Ptflg=2 : Graph thermopile output
2735 ! For Ptflg=3 : Graph temperature probe output
2740 ! B$ passes the plot title
2745 OPTION BASE 1
2750 COM /Data/ Dfiles[20] File[s][16],Mount_id$[16]
2755 COM /Data/ V[3000,2],E(3000,2),F(500,2),N[100,2],Header(27)
2760 NO=Header(9) !Total # of measurements (array size)
2765 ALLOCATE A$(80) !String for title
2770 ALLOCATE P(N,2) !Plotting array
2775 SYS prt=VAL(SYSTEM$("SYSTEM PRIORITY")) !Determine system priority
2780 Lcl_prt=Sys_prt+1 !Set local priority 1 higher for ON KEY
2785 G_Flg=1 !Set flag to display graph
2790 FOR N=0 TO 19
2795 ON KEY N LABEL " " GOTO TOP
2800 NEXT N
2805 ON KEY 0 LABEL " PREV MENU " ,Lc1_prt,y GOTO Exit
2810 ON KEY 1 LABEL " DUMP plot " ,Lc1_prt,y GOSUB Dump
2815 ON KEY 5 LABEL "CHANGE x-axis " ,Lc1_prt,y GOSUB Chg_x
2820 ON KEY 5 LABEL "CHANGE y-axis " ,Lc1_prt,y GOSUB Chg_y
2825 ON KEY 6 LABEL "CHANGE y-axis " ,Lc1_prt,y GOSUB Chg_y
2830 Top LOOP
2835 IF G_flg THEN GOSUB Graph.
2840 IF Chg_flg THEN GOSUB Graph_xy
2845 END LOOP
2850 !
2855 Chg_x:
2860 Ans$="" !Change x axis range
2865 DISP "New Tmin <" ;Tmin/60;"> " ; !Make sure dummy is empty
2870 INPUT Ans$ !Ask if change for Tmin
2875 IF Ans$><" THEN Tmin=60.*VAL(Ans$) !Get response
2880 Ans$="" !Make sure dummy is empty
2885 DISP "New Tmax <" ;Tmax/60;"> " ; !Ask if change for Tmax
2890 INPUT Ans$ !Get response
2895 IF Ans$>>" THEN Tmax=60.*VAL(Ans$) !Get response
2900 Ans$="" !Make sure dummy is empty
2905 Chg_flg=1 !Indicate the change
2910 RETURN
2915 !
2920 Chg_y:
2925 DISP "New Vmin <" ;Vmin;"> " ; !Graphs thermopile nanovolt output
2930 INPUT Ans$ !Ask if change for Vmin
2935 IF Ans$>>" THEN Vmin=VAL(Ans$) !Get response
2940 Ans$="" !Make sure dummy is empty
2945 DISP "New Vmax <" ;Vmax;"> " ; !Ask if change for Vmax
2950 INPUT Ans$ !Get response
2955 IF Ans$<>" THEN Vmax=VAL(Ans$) !Get response
2960 Chg_flg=1 !Indicate the change
2965 RETURN
2970 !
2975 Dump:
2980 OUTPUT KBD;"K";
2985 CONTROL 1,12,11
2990 GOSUB Graph_xy
2995 OUTPUT KBD;"N";
3000 CONTROL 1,12,0
3005 RETURN
3010 !
3015 Graph: !Main graph routine
3020 SELECT Ptflg
3025 CASE 1
3030 MAT P= V !For power meter
3035 CASE 2 !For thermopile
3040 MAT P= E CASE 3 !For temperature - thermo time in Col 1
3045 MAT P= E FOR N=1 TO No
3050 FOR N=1 TO No
3055 P[N,2]=TP(N)
3060 NEXT N !Temp into Col 2
3065 !
3070 END SELECT !Check for elapsed or absolute time
3075 IF P[N,1]>1.E+6 THEN !Change to elapsed
3080 FOR N=1 TO No
3085 P[N,1]=P(N,1)-Header(2) !Check for elapsed or absolute time
3090 NEXT N !Change to elapsed
3095 END IF !Find Max time
3100 Timax=P(No,1) !Find Max time
3105 Timin=P(No,1) !Find the plot max/min
3110 Vmax=P(1,2) !Find the plot max/min
3115 Vmin=P(1,2) !Find the plot max/min
3120 FOR N=2 TO No !Find Vpmax=P(N,2)
3125 IF Vpmax>P(N,2) THEN Vpmax=P(N,2) !Find Vpmin=P(N,2)
3130 NEXT N !Find Vpmin=P(N,2)
3135 Vpmax=Vpmax+.05*ABS(Vpmax-Vpmin) !Find the plot max + 5%
3140 Vpmin=Vpmin-.05*ABS(Vpmax-Vpmin) !Find the plot min - 5%
3145 Graph_xy: !Alternate entry point
3150 Graph_xy: !Clear screen
3155 GINIT !All labels ref. top center
3160 OUTPUT KBD;"K"; !Add date to title
3165 LORG 6 !Write title
3170 PEN 5 !Move to top for title label
3175 MOVE 75,100 !Move to top for title label
3180 CSIZE 3.0 !Smaller letters
3185 AS=DATE$(TIMEDATE)&," &TIME$(TIMEDATE)&," &AS !Add date to title
3190 AS=B$," !Write title
3195 LABEL A$ !Move for sub title
3200 MOVE 75,95 !Move for sub title
3205 DATA FILE: "&Dfile$" !PROGRAM: "&File$"
3210 LABEL A$ !Write title
3215 CSIZE 4.0 !Little larger letters
3220 MOVE 70,12 !For horizontal axes label
3225 LABEL "TIME (min)" !Write label
3230 MOVE 0,55 !For vertical axis label
3235 LDIR PI/2 !Rotate 90
3240 SELECT Ptflg
3245 CASE 1 !Horizontal scale range in seconds
3250 LABEL "MILLIVOLTS" !For power meter
3255 CASE 2 !For thermopile
3260 LABEL "MICROVOLTS" !For thermopile
3265 CASE 3 !For temperature
3270 LABEL "DEGREES C" !For temperature
3275 END SELECT !Back to horizontal
3280 LDIR 0 !Subset of screen area
3285 VIEWPORT 20,125,16,90 !Cure for WINDOW error
3290 MOVE 0,0 !Scale factors
3295 ! Set up x-axis tic and label spacing
3300 ! Range-Tmax-Tmin
3305 !Horizontal scale range in seconds
3310 !
3315 SELECT Range !For Range <= 90 min
3320 CASE <5400 !X-tics every 1 min
3325 X=60 !10 tics/major div
3330 Xtic=10 !Labels every 10 min
3335 Stp=600 !For 300 min >Range> 120 min
3340 CASE <18000 !X-tics every 10 min
3345 X=600 !3 tics/major div
3350 Xtic=3 !Labels every 30 min
3355 Stp=1800 !For 600 min >Range> 300 min
3360 CASE <36000 !X-tics every 10 min
3365 X=600

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4715 RETURN
4720 !
4725 Ld_1400: ! Load from /USERS/FRC:,1400
4730 IF N_name$="" THEN
4735   DISP "I have not been given a file name."
4740   WAIT 1
4745   DISP ""
4750   GOTO R1400
4755 END IF
4760 D14file$="/USERS/FRC/"&N_name$:&,1400"
4765 N_name$=""
4770 GOSUB Get_14data
4775 GOTO Exit
4780 RETURN
4785 R1400:RETURN
4790 !
4795 C_name:
4800 KEY LABELS OFF
4805 INPUT "Input the new file name",N_name$
4810 MSG F1g=1
4815 KEY LABELS ON
4820 RETURN
4825 !
4830 Get_data:
4835 MAT E=(0)
4840 MAT V=(0)
4845 MAT F=(0)
4850 MAT TP=(0)
4855 ASSIGN @Path1 TO Dfile$ !Open & set file pointer at beginning
4860 ! Input all test information and all files
4865 ENTER @Path1;File$,Mount_id$,Header(*) !Redim arrays to fit data
4870 CALL New_size
4875 IF Header(4) THEN !The EE array is present
4880   ENTER @Path1;E(*),V(*),F(*),Tp(*) Ne(*) !Problem with Pwr(*) - force recalc
4885 ELSE
4890   ENTER @Path1;E(*),V(*),F(*),Tp(*) !of EE & thus Pwr(*)
4895 END IF
4900 ASSIGN @Path1 TO *
4905 Dfile$=@Path1;File$[1,10]
4910 Header(4)=0
4915 RETURN
4920 !
4925 Get_14data:
4930 KEY LABELS OFF
4935 MAT E=(0)
4940 MAT V=(0)
4945 MAT F=(0)
4950 MAT TP=(0)
4955 ASSIGN @Path1 TO D14file$ !Open & set file pointer at beginning
4960 ! Input all test information and all files
4965 ENTER @Path1;File$,Mount_id$,Header(*) !Redim arrays to fit data
4970 CALL New_size
4975 IF Header(4) THEN !The EE array is present
4980   ENTER @Path1;E(*),V(*),F(*),Tp(*) Ne(*)
4985 ELSE
4990   ENTER @Path1;E(*),V(*),F(*),Tp(*) !Pwr(*) array not present
4995 END IF
5000 ASSIGN @Path1 TO *
5005 Dfile$=D14file$[12,21]
5010 Header(4)=0
5015 RETURN
5020 !
5025 Exit:OFF KEY
5030 SUBEND
5035 !
5040 Ef:
5045

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5385 PRINT Freq
5386 PRINT R$2,Edc,Erf,Eff
5395 RETURN
5400
5405 EXIT:CONTROL 1,12:0 !Turn labels back on
5410 SUBEND
5415 ! * * * * * * * * * * * * * * * * * * * * * * * * * * *
5420 V_avg: SUB V_avg(Chk_f1g,Chk_freq,Freq_no,Vdc,Vrf) !Average V's from raw data
5425 COM /Data/ Dfiles[20].File1$[16],Mount_ids$[16]
5430 COM /Data/ Dfiles[20].File1$[20],F(3000,2),F(500,2),Ne(100,2),Header(27)
5435 ! Chk_flg: 1 = Displays the data and results for a visual check
5440 ! " : 0 = Computes average without displaying result(s).
5445 ! " : -1 = Displays the data and results for a visual check
5450 ! Chk_freq: The single frequency for a visual check.
5455 ! Freq_no: No. of freq (place in the series of frequencies) for which
5460 ! the average is to be determined.
5465 ! Vdc: The returned calculated average value of Vdc.
5470 ! Vrf: The returned calculated average value of Vrf.
5475 ! OPTION BASE 1
5480 COM /Data/ Dfiles[20].File1$[16],Mount_ids$[16]
5485 COM /Data/ Dfiles[20].File1$[20],E(3000,2),F(500,2),Ne(100,2),Header(27)
5500 COM /Data/ Af(10,3),INTEGER TP(3000)
5510 DIM B$(60)
5515 !
5520 Vdc=0 !Zero out variable
5525 Vrf=0 !Zero out variable
5530 Freq=INT(F(Freq_no,1)*1.E+3)/1.E+3 !Get the frequency in GHz
5535 N1=F(Freq_no,2) !Meas No. at start of freq
5540 Vst-V(N1-1,2) !Vdc at start of freq
5545 FOR N=N1 TO Header(9) !Look for the next RF-off reading
5550 IF V(N,2)>9*Nst AND V(N,2)<1.*r$1 THEN GOTO Jump_out !Sum up the rf readings
5555 Vst=Vr$+V(N,2)
5560 Jump_out:N2=N !Meas No. at end of freq
5565 Vsp=(Vst-Vsp)/2 !Vdc at end of freq
5570 Vdc=(Vst-Vsp)/2 !Avg the two end points
5575 Plt1g=1 !Plot V
5580 Vf1g=1 !For Vdc
5585 OUTPUT Vdc$ USING "#,DDDD,DDDD";Vdc:1,.B+3
5590 B$="Vdc="&Vdc$&" mv at "&V1A$&Freq" & " GHz"
5595 IF Chk_f1g>0 THEN CALL Graph_check(Vf1g,B$,Vdc,N1,N2,0,0,S_f1g)
5600 IF Chk_f1g<0 AND FreqChk.freq THEN CALL
5605 Graph_check(P1t1g,Vf1g,B$,Vdc,N1,N2,0,0,S_f1g)
5610 Vrf=Vrf/(N2-N1) !Vrf - compute the average
5615 OUTPUT Vrf$ USING "#,DDDD,DDDD";Vrf:1,.B+3
5620 B$="Vrf="&Vrf$&" mv at "&V1A$&Freq" & " GHz"
5625 IF Chk_f1g>0 THEN CALL Graph_check(P1t1g,Vf1g,B$,Vrf,N1,N2,0,0,S_f1g)
5630 IF Chk_f1g<0 AND FreqChk.freq THEN CALL
5635 Graph_check(P1t1g,Vf1g,B$,Vrf,N1,N2,0,0,S_f1g)
5640 OFF KEY
5645 SUBEND ! * * * * * * * * * * * * * * * * * * * * * * * * * *
5650 E_avg: !SUB E_avg(Chk_f1g,Chk_freq,Freq_no,Edc,Erf) !Determine avg E's
5655 ! Chk_flg: 1 = Displays the data and results for a visual check
5660 ! " : 0 = Computes average without displaying result(s).
5665 ! " : -1 = Displays the data and results for a visual check
5670 ! S_f1g: 1 = step thru stability test routine
5675 ! Chk_e0: 1 if EOF check is in data set
5680 ! Chk_f1g: The single frequency for a visual check.
5685 ! Freq_no: No. of freq (place in the series of frequencies) for which
5690 ! the average is to be determined.
5695 ! Edc: The returned calculated average value of Edc.
5700 ! Erf: The returned calculated average value of Erf.
5705 ! Lss: The no. of data points averaged in Find_trend.
5710
5715 ! OPTION BASE 1
5720 INTEGER N
5725 COM /Data/ Dfiles[20].File1$[20],F(3000,2),F(500,2),Ne(100,2),Header(27)
5730 COM /Data/ Af(10,3),INTEGER TP(3000)
5735 COM /Init_stats Tcv,Rev,Enr,Sdhr,Volts(100),INTEGER Mode,Lss
5740 COM /Flag/ S_f1g
5745 DIM B$(60)
5750 ! Set flag if EOF check is in data set
5755 ! Get the total # of freq measured
5760 ! Edc=Header(5)
5765 ! Edc=0
5770 ! Edf=0
5775 ! Freq=INT(F(Freq_no,1)*1.E+3)/1.E+3 !Get the frequency in GHz
5780 ! Chk_e0=Header(19)
5785 ! No_Freq=Header(5)
5790 ! E0=0
5795 ! Edc=0
5800 ! Edf=0
5805 ! Freq=INT(F(Freq_no,1)*1.E+3)/1.E+3 !Get the frequency in GHz
5810 ! *****
5815 ! Set flag if EOF check is in data set
5820 ! Get the total # of freq measured
5825 ! Edc=Header(5)
5825 ! E0=Average !Calculate E0
5830 ! E0=0
5835 ! First end point for EOF average
5840 ! Meas No. at end of dc off
5845 ! Start Lss points (Lss/2 min) back
5850 ! Stop point
5855 ! Avg Points
5860 ! *****
5865 ! Second end point for EOF average
5870 ! Y1 for linear thermopile correction
5875 ! X1=PO1 !X1 for linear thermopile correction
5880 ! Y1=PO1 !Y1 for linear thermopile correction
5885 ! Nf=Header(9)
5890 ! Nst=Nf-Lss !Start average back Lss/2 min from end
5895 ! NSP=NSN-Lss-1 !Average for Lss points (Lss/2 min)
5900 ! FOR N=Nst TO NSP !Start and stop as indicated above
5905 ! ED2=E0+E(N,2)
5910 ! NEXT N
5915 ! E0=ED2/(NSP-NSN+1) !Average
5920 ! X2=INT((NSP-NSN)/2) !X2 for linear thermopile correction
5925 ! Y2=PO2 !Y2 for linear thermopile correction
5930 ! E0=Y1+Y2)/2 !AVG without linear correction
5935 ! Header(15)=E0 !Put avg value in header
5940 ! A0=(Y2-Y1)/(X2-X1) !A0 - slope for linear correction
5945 ! B0=(X2*Y1-X1*Y2)/(X2-X1) !B0 - intercept for a+bx correction
5950 ! END IF
5955 ! *****
5960 ! *****
5965 ! *****
5970 ! IF F(1,2) !Meas No. at start of rf (1st freq)
5975 ! Nst=Nf-F(2,2) !If EOF checked, jump that data
5980 ! NSP=NSN-1 !Start Lss points (Lss/2 min) back
5985 ! FOR N=NSN TO NSP !Stop point
5990 ! Edc=EDC1+E(N,2) !Avg Points
5995 ! *****
6000 ! *****
6005 ! *****
6010 ! *****
6015 ! *****
6020 ! *****
6025 ! *****
6030 ! *****
6035 ! *****
6040 ! *****
6050 ! *****

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6710 Chg_v:
    avg
    Ans$=""
    6715 DISP "New Vavg < " ;Vavg;" > ";
    INPUT Ans$           !Ask for changed value
    6725 IF Ans$>" " THEN Vavg=VAL(Ans$)
    6730 B$(5,12)=VAL$(Vavg*1.E+6) !Put new value in label
    G_Flg=1               !Indicate the change
    RETURN
    6745 Dump:
    OUTPUT KBD;"K";
    6755 CONTROL 1,12,I
    6760 GOSUB Graph_xy
    6765 OUTPUT KBD;"N";
    6770 CONTROL 1,12,I
    6775 RETURN
    6780 !
    6785 !Setup routine
    6790 IF Pltf_lg THEN
    6795 MAT p= V
    6800 ELSE
    6805 MAT p= E
    6810 END IF
    6815 IF P(No,1)>1.E+6 THEN
    6820 FOR N=1 TO No
    6825     P(N,1)=P(N,1)-Header(2)
    6830 NEXT N
    6840 END IF
    6845 GOSUB Vavg
    6850 RETURN
    !
    6855 Graph_xy:
    6860 OUTPUT KBD;"K";
    6870 GINIT
    6875 LORG 6
    6880 PEN 5
    !
    6885 CSIZE 3.4
    6890 MOVE 64.98
    6895 Timedel=Header(2)           !Get time-date of measurement
    6900 A$=DATE$"(Timedel)&","&TIME$(Timedel)" DATA FILE: "&Dfile$&" &A$!
    6910 A$=MOUNT: "&Mount_ids$&" !Write title
    6915 LABEL A$                  !
    6920 MOVE 73.25
    6925 CSIZE 4.5
    6930 LABEL B$                  !
    6940 !
    6945 CSIZE 4.0
    6950 MOVE 10.12
    6955 MOVE 70.12
    6960 LABEL "TIME (min)"        !
    6965 MOVE 0.55
    6970 LDIR PI/2
    6975 IF Pltf_lg=1 THEN
    6980     LABEL "MILLIVOLTS"
    6985 ELSE
    6990     LABEL "MICROVOLTS"
    6995 END IF
    7000 LDIR 0
    7005 PEN 1
    7010 VIEWPORT 20.125,1.6,90
    7015 MOVE 0,0
    7020 ! Set up x-axis tic and label spacing
    7025 Range=Timax-Timin
    7030 SELECT Range
    7040 CASE <=5400
    !
    7045 X=60
    Xti=10
    7050 Stp=600
    CASE <=18000
    X=600
    Xti=3
    7055 Stp=1800
    CASE <=36000
    X=600
    Xti=6
    7060 Stp=3600
    CASE >36000
    X=600
    Xti=12
    7065 Stp=3600
    CASE >18000
    X=600
    Xti=16
    7070 Stp=36000
    CASE <=30 min
    X=600
    Xti=16
    7075 Stp=36000
    CASE >30 min
    X=600
    Xti=16
    7080 Stp=36000
    CASE <=10 min
    X=600
    Xti=16
    7085 Stp=36000
    CASE >10 min
    X=600
    Xti=16
    7090 Stp=36000
    CASE >60 min
    X=600
    Xti=16
    7095 Stp=36000
    CASE >600 min
    X=600
    Xti=16
    7100 Stp=36000
    CASE >600 min
    X=600
    Xti=16
    7105 Stp=36000
    CASE >120 min
    X=600
    Xti=16
    7110 Stp=36000
    CASE >120 min
    X=600
    Xti=16
    7115 Stp=7200
    !
    7120 END SELECT
    Y=(Vmax-Vmin)/10
    AXES X,Y,Timin,Vmin,Xtic,1,4
    AXES X,Y,Timax,Vmax,Xtic
    CLIP OFF
    CSIZE 3.5
    FOR I=0 TO Timax-Timin STEP Stp
    MOVE Timin+I,Vmin-Y/10
    LABEL USING "#,DDDD.DDD";(Timin+I)/60
    NEXT I
    !
    7130 !REF. center rt. end
    7135 place
    7140 !Label for power meter output graph
    7145 !Allow labels outside viewport
    7150 !Smaller characters for axis labels
    7155 !Label every ? on X axis
    7160 !Just below x axis
    7165 !NO CR/LF
    !
    7170 LORG 8
    IF Pltf_lg THEN
    7175 FOR I=Vmin TO Vmax STEP Y
    7180     !Label every Y on Y axis
    7185 MOVE Timin-.01,I
    7190     !To the left of X axis
    7195 LABEL USING "#,MDDD.DDD";1.E+3*I !No CR/LF
    NEXT I
    !
    7200 ELSE
    7205 FOR I=Vmin TO Vmax STEP Y
    7210     !Label every Y on Y axis
    7215 MOVE Timin+.01,I
    7220 LABEL USING "#,MDDD.DDD";1.E+6*I !No CR/LF - microvolts
    NEXT I
    !
    7225 END IF
    7230 PEN 2
    7235 CLIP ON
    7240 FOR I=1 TO No
    7245     PLOT P(Count,1),P(Count,2)
    7250 NEXT Count
    7255 PENUP
    7260 PLOT Nst*Delt,Vmin
    7265 LINE TYPE 5
    7270 PLOT Timin,Vavg
    7275 PLOT Timax,Vavg
    7280 PENUP
    7285 PLOT Nst*Delt,Vmin
    7290 PLOT Nst*Delt,Vmax
    7295 PENUP
    7300 PLOT Nsp*Delt,Vmin
    7305 PLOT Nsp*Delt,Vmax
    7310 PENUP
    7315 G_flg=0
    7320 !Don't replot
    7325 Chg_Flg=0
    7330 RETURN
    !
    7335 !
    7340 Sexit:S_flag=1
    7345 Exit:OFF KEY
    7350 KEY LABELS OFF
    7355 GINIT
    7360 SUBEND
    7365 ! * * * * *
    7370 Settle_2:
    7375 SUB Settle_2(N1,N2,Erf,Nmid,Nst,Nsp,S_flag)
    !

```

```

7385 ! N1: Frequency starting point
7385 ! N2: Frequency stopping point
7390 ! Nst: Beginning of settled run
7395 ! Nsp: End of settled run
7400 ! Erf: is the final settled value
7405 ! Nmid: is the mid point of the array range from which Erf came
7410 ! S_flg: A flag to pause after every call to Find_trend subroutine
7415 !
7420 OPTION BASE 1
7430 INTEGER I,N
COM /Data/ Dfiles[20].File1[$16].Mount_ids[$16]
7435 COM /Data/ V3000(2),E(3000,2),F(500,2),Ne(100,2),Header(27)
7440 COM /Data/ Af(10,3),INTEGER Tp(3000)
7445 COM /Init_stats/ Tcv,Rcv,Env,Sahr.Volts(100),INTEGER Mode,Lss
7450 !
7455 Erf=0
7460 Mode=1
7465 N=N1
7470 WHILE N+Lss-1<N2 AND Stable_run=0 !Either
7475 FOR I=1 TO Lss !Data for Find_trend
7480 Volts(I)=1.05+6*E(I-1+N,2) !Data to microvolts
7485 CALL Find_trend(Stable_run) !Dom's routine
7490 IF S_flg THEN PAUSE
7495 FOR N=NST TO NSP
7500 ERf=Er!+E(N,2)
7505 NEXT N
7510 NST=N-1
7515 NSP=N+Lss-2
7520 FOR N=NST TO NSP
7525 ERf=Er!+E(N,2)
7530 NEXT N
7535 ERf=ERf/(NSP-NST+1)
7540 Nmid=INT((NST+NSP)/2)
7545 SUBEND
7550 ! * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
7555 !Graph efficiency or power
7560 Graph_n_p(P_flg)
7565 SUB Graph_n_p(P_flg)
7570 OPTION BASE 1
7575 COM /Data/ Dfiles[20].File1[$16].Mount_ids[$16]
7580 COM /Data/ V3000(2),E(3000,2),F(500,2),Ne(100,2),Header(27)
7585 COM /Data/ Af(10,3),INTEGER Tp(3000)
7590 COM /Graph.pct/ Pwr(100,2)
7595 NO=Header(A$190)
7600 ALLOCATE P(No,2)
7605 ALLOCATE P(No,2)
7610 REDIM Pwr(No,2)
7615 Bid_Header(3)
7620 BidsVALS(Bid)
7625 Sys_prt=VAL(SYSTEM("SYSTEM PRIORITY"))
7630 Lcl_prt=SYS_PRTY+1
7635 G_flg=1
7640 CONTROL 1,12,0
7645 FOR N=0 TO 19
7650 ON KEY N LABEL " GOTO TOP
7655 NEXT N
7660 ON KEY 0 LABEL " PREV MENU " Lcl_prt GOTO Exit
7665 ON KEY 5 LABEL " CHANGE x-axis " Lcl_prt GOSUB Chg_x
7670 ON KEY 6 LABEL " CHANGE y-axis " Lcl_prt GOSUB Chg_y
7675 ON KEY 1 LABEL " DUMP plot " Lcl_prt GOSUB Dump
7680 ON KEY 2 LABEL " LIST result " Lcl_prt GOSUB List
7685 ON KEY 7 LABEL " PRINT result " Lcl_prt GOSUB Print
7690 Top:LOOP
7695 IF G_flg THEN GOSUB Graph_Setup
7700 IF Chg_flg THEN GOSUB Graph_xy
7705 END LOOP
7710 !
7715 Chg_x:
! Change x axis range

! Make sure dummy is empty
7720 Ans$=""
7725 DISP "New Xmin <" ;Xmin;" >" ;
7730 INPUT Ans$ !Get response
7735 IF Ans$<>" " THEN Xmin=VAL(Ans$) !Ask if change for Xmin
7740 Ans$=" "
7745 DISP "New Xmax <" ;Xmax;" >" ;
7750 INPUT Ans$ !Get response
7755 IF Ans$<>" " THEN Xmax=VAL(Ans$) !Ask if change for Xmax
7760 Ans$=" "
7765 Chg_flg=1 !Make sure dummy is empty
7770 RETURN !Indicate the change

! Graph thermopile nanovolt output
7775 Chg_Y:
7780 DISP "New Ymin <" ;Ymin;" >" ;
7785 INPUT Ans$ !Get response
7790 IF Ans$<>" " THEN Ymin=VAL(Ans$) !Ask if change for Ymin
7795 Ans$=" "
7800 DISP "New Ymax <" ;Ymax;" >" ;
7805 INPUT Ans$ !Get response
7810 IF Ans$<>" " THEN Ymax=VAL(Ans$) !Ask if change for Ymax
7815 IF Ans$<>" " THEN Ymax=VAL(Ans$) !Get response
7820 Chg_flg=1 !Indicate the change
7825 RETURN

!Graphs calculated effective efficiency
7830 Dump:
7835 OUTPUT KBD;"K";
7840 CONTROL 1,12;1
7845 GOSUB Graph_xy
7850 OUTPUT KBD;"N";
7855 CONTROL 1,12;0
7860 RETURN
7870 !
7875 List:
7880 P_flg=0
7885 CALL Print_ne(P_flg)
7890 RETURN
7895 !
7900 Print:
7905 P_flg=1
7910 CALL Print_ne(P_flg)
7915 RETURN
7920 !
7925 Graph_Setup:
7930 IF P_flg THEN
7935 MAT P=Pwr
7940 IF Header(21) THEN MAT SORT P(*,1) !POWER
7945 Xmir=0 !Beginning point: x axis
7950 Xmax=20 !End point: x axis
7955 Ymir=.99 !Beginning point: y axis
7960 Ymax=10.1 !End point: y axis
7965 !
7970 MAT P=Ne !EFFICIENCY
7975 IF Header(21) THEN MAT SORT P(*,1) !IF random freq order
7980 Xmir=0 !Beginning point: x axis
7985 Xmax=20 !End point: x axis
7990 Ymir=.90 !Beginning point: y axis
7995 Ymax=1.0 !End point: y axis
8000 END IF
8005 Chg_flg=1 !Indicate the change
8010 RETURN
8015 !
8020 Graph_xy:
8025 OUTPUT KBD;"K";
8030 GINIT
8035 LORG 6
8040 PEN 5
8045 CSIZE 5.0
8050 MOVE 64,100
8055 !Size of title
8060 Locate it

```

```

060 IF Pflg THEN !Put graphics back to default
065   LABEL "COAX MOUNT - RF POWER LEVEL"
070 ELSE
075   LABEL "COAX MOUNT - EFFECTIVE EFFICIENCY"
080 END IF
085 !
090   CSIZE 3,5 !Size of sub title
095   MOVE #4,4 !Move for sub title
100   TIMEdate$=Header(2) !Get time-date of measurement
105   A$=DATE$(TIMEdate$)
110   AS$="MOUNT_&Mount_id$&" DATE :"&AS$ !Data file name
115   LABEL AS !Write sub title
120   CSIZE 4,5 !Change size
125   MOVE #0,1.2 !For horizontal axes label
130   LABEL "FREQUENCY (GHz)" !Write label
135   MOVE #0,55 !For vertical axes label
140   LDIR P1/2 !Rotate 90
145   IF Pflg THEN !EFFICIENCY
150   LABEL "POWER (mW)" !EFFICIENCY
155   ELSE
160   LABEL "PERCENT" !EFFICIENCY
165   END IF !Back to horizontal
170   LDIR 0
175   PEN 1 !POWER
180   IF Pflg THEN !Subset of screen area
185   VIEWPORT 18,125,16,88 !EFFICIENCY
190   ELSE
195   VIEWPORT 14,125,16,88 !Subset of screen area
200   END IF !Subset of screen area
205   WINDOW Xmin,Xmax,Ymin,Ymax !Scale factors
210   I Set up x-axis tic and label spacing
215   X=.25 !X-tics every 0.25
220   Xtic=4 !4 tics major div
225   Stpx=1 !Label every 1 GHz
230   Y=(Ymax-Ymin)/20 !Calculate vertical ticks
235   AXES X,Y,Xmin,Ymin,Xtic,2,4 !Draw axes with ticks at the right
240   place !Same ticks on the other sides
245   CLIP OFF !Allow labels outside viewport
250   CSIZE 3,5 !Smaller characters for axis labels
255   FOR I=0 TO Xmax-Xmin STEP Stpx !Label every ? on Y axis
260   MOVE Xmin+.01,I !Just below x axis
265   LABEL USING "#,DDD";I !No CR/LF
270   NEXT I !REF. center rt. end
275   LORG 8 !POWER
280   IF Pflg THEN !Label every ? on Y axis
285   FOR I=Ymin TO Ymax STEP 2*Y !To the left of X axis
290   MOVE Xmin-.01,I !Power - mW
295   LABEL USING "#,DDD.D";I !Keep plot inside viewport
300   !EFFICIENCY !Loop to plot readings
305   ELSE !Label every ? on Y axis !Plot the point
310   FOR I=Ymin-.01,I !To the left of X axis
315   MOVE Xmin+.01,I !Label USING "#,DDD.D";I!00*I!NO CR/LF - percent
320   LABEL USING "#,DDD.D";I !Don't replot
325   NEXT I !Don't replot
330   END IF !Alternate entry point
335   PENDUP !Frequency
340   CLIP ON !Power in mW
345   FOR Count=1 TO No PLOT P(Count,1),P(Count,2) !Power CORRECTED"
350   NEXT Count !Power in mW
355   G_f1g=0 !Frequency
360   Cng_f1g=0 !Power in mW
365   RETURN !Power in mW

```

```

8735 ! PRINT TAB(39),#;DD,DDD";1.00038+.00095*Ne1(N,1)^.452 !Correction factor
8740 G2: PRINT USING "#,DD,DDD";1.00038+.00095*Ne1(N,1)^.452
8745 !
8750 ! PRINT TAB(58),#;DD,DDD";100*Ne1(N,2)/(1.00038+.00095*Ne1(N,1)^.452) !Raw efficiency
8755 G3: PRINT USING "#,DD,DDD";100*Ne1(N,2)/(1.00038+.00095*Ne1(N,1)^.452)
8760 !
8765 ! PRINT TAB(70),#;DD,DDD";100*Ne1(N,2)
8770 ! PRINT USING "DD,DDD";100*Ne1(N,2)
8775 !
8780 ! RETURN
8785 !
8790 Exit: !PRINT IS CRT
8795 !
8800 SUBEND
8805 ! * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
8810 Soft_init: !SUB Soft_init(Z_flg)
8815 ! This is the "main" subprogram for software initialization.
8820 !The initial default entries for each calorimeter are in the subs,
8825 !Default thru Default_6 (following this subprogram).
8830 !Default thru Default_6 (following this subprogram).
8835 !To change the initial menu default choices, goto label Default_sel,
8840 !(in the Menu subprogram).
8845 OPTION BASE 1
8850 COM /Data/ Dfiles[20],File1$[16],Mount_id$[16]
8855 COM /Data/ V(3000,2),E(3000,2),F(500,2),Ne(100,2),Header(27)
8860 COM /Data/ Af(10,3),INTEGER_Tp(3000)
8865 COM /Menu/ INTEGER_Men(17,20)
8870 COM /Init_stats/ Tcv,Rcv,Err,Sahr,Volts(100),INTEGER_Mode,Lss
8875 COM /Screen_update/ Count,Cftime,Freq,Pwr
8880 COM /Screen_update2/ Avg,Sd
8885 COM /Stats_2/ R,Prob,INTEGER_Nruns
8890 DFfile$="" !Clear data file name
8895 MAT V=(0) !Clear old data file
8900 MAT E=(0) !
8905 MAT F=(0) !
8910 MAT Ne=(0) !
8915 MAT Header=(0) !Clear old header
8920 Count=0 !Reset measurement counter
8925 !Then set some new defaults
8930 Header(9)=2400 !No. of measurements
8935 Header(11)=30 !Interval between meas (sec)
8940 Header(12)=10 !Power in milliwatts
8945 Header(16)=0 !Mount pre-bias
8950 Header(19)=0 !Zero correction flag
8955 Header(20)=0 !Set auto freq flag
8960 Header(21)=0 !Set random freq order flag
8965 !Stats init
8970 Lss=18 !No. in avg
8975 Rcv=-2.5 !Tuning constant
8980 Tcv=.25 !Expected No of runs
8985 Enr=(.2*0*Lss-.1)*3.0
8990 Sdnr=SQR((16.0*Lss-29.0)/90.0) !SD of No of runs
8995 Model=1 !For stats
9000 R=0 !
9005 Prob=0 !
9010 Nruns=0 !
9015 Avg=0 !
9020 Sd=0 !
9025 Pwr=0 !
9030 !
9035 Menu_no=0 !Call for the first menu
9040 No_rows=8 !Min=1, max=17
9045 No_cols=1 !Min=1, max=16 if No_rows >=6
CALL MENU(Menu_no, No_rows, No_cols) !Find the option selected
FOR N=1 TO No_rows
9055 IF Men(N,1) THEN Menu_no=N !For the second menu
NEXT N
9065 No_rows=8

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10095 COM /Data/ Dfiles[20],File1$[16],Mount_id$[16]
10100 COM /Data/ V(3000,2),E(3000,2),F(500,2),Ne(100,2),Header(27)
10105 COM /Data/ Af(10,3),INTEGER TP(3000)
10110 /F19g5/ Manual_freqs
10115 DIM A$(180),B$(190),C_sum(20),Screen$(117,20)[80]
10120 Para: !
10123 Spacing=2
10130 Wrap=2
10135 No_rows=MAX(1,No_rows)
10140 No_rows=MIN(17,No_rows)
10145 No_cols=MAX(1,No_cols)
10150 No_cols=MIN(40,No_cols)
10155 REDIM Screen$(1:No_rows,1:No_cols),Men(1:No_rows,1:No_cols),C_sum(1:No_cols)

10160 Ptrs:CHR$(129)&CHR$(136)&=">"&CHR$(138)&CHR$(128)
10165 Clear$=" "
10170 GOSUB Defaults
10175 CLEAR SCREEN
10180 GOSUB Scrn.Print
10185 Sys_prt=VAL(SYSTEM$("SYSTEM PRIORITY"))
10190 Lc1_prt=VAL(Sys_prt+1)
10195 ON KNOB .03,Lc1_prt GOSUB Knob_service
10200 WAIT .05
10205 FOR N=0 TO 19
10210 ON KEY N LABEL "" Lc1_prt GOTO Idle
10215 NEXT N
10220 ON KEY 0 LABEL " CONTINUE " ,Lc1_prt GOTO Exit
10225 IF Menu_no=0 THEN
10230 ON KEY 5 LABEL "SELECT OPTION" Lc1_prt GOSUB Check
10235 ELSE
10240 ON KEY 5 LABEL "CHANGE DEFAULT" ,Lc1_prt GOSUB Check
10245 END IF
10250 ON KBD Lc1_drt GOSUB Kb_d_service
10255 KEY LABELS ON
10260 Idle:LOOP
10265 END LOOP
10270 !
10275 Defaults:
10280 params
10285 SELECT Menu_no
10290 CASE =1
10295 CALL Default1
10300 CASE =2
10305 CALL Default2
10310 CASE =3
10315 CALL Default3
10320 CASE =4
10325 CALL Default4
10330 CASE =5
10335 CALL Default5
10340 CASE =6
10345 CALL Default6
10350 CASE =7
10355 CALL Default7
10360 CASE =8
10365 CALL Default8
10370 END SELECT
10375 RETURN
10380 !
10385 Scrn.Print:
10390 IF Menu_no>0 THEN
10395 CALL Scrn1(Screen$(*))
ELSE
10400 CALL Scrn0(Screen$(*))
END IF
10405 MAT Men= (0)
10410 IMAGE #_22
10415 IMAGE #,_32
10420

Max_ctr=No_rows*No_cols
10430 IF Menu_no=0 THEN
10435 PRINT TABXY(28,1);CHR$(136);;"SYSTEM INITIALIZATION MENU";CHR$(138)
10440 IF Header(3) THEN
10445 PRINT TABXY(30,1);CHR$(136);;"WR-";Header(3);;" DEFAULT
10450 PARAMETERS";CHR$(138)
10455 ELSE
10460 PRINT TABXY(31,1);CHR$(136);;"COAX DEFAULT PARAMETERS";CHR$(138)
10465 END IF
10470 Ctr=0
10475 FOR Col=1 TO No_cols
10480 FOR Row=1 TO No_rows
10485 Ctr=Ctr+1
10490 IF Max_ctr<100 THEN OUTPUT B$ USING 10415;Ctr
10495 IF Max_ctr>=100 THEN OUTPUT B$ USING 10420;Ctr
10500 B$=B$&Screens(Row,Col)=B$
10505 Screens(Row,Col)=B$
10510 Str=LEN(B$)
10515 CALL Sc(0,0,Spacing*(Row-1)+1,(St1+2)*(Col-1)+3,B$)
10520 NEXT Row
10525 DEFaults:
10530 NEXT Col
10535 IF Menu_no>0 THEN
10540 Col=1
10545 IF Header(20) THEN
10550 Row=1
10555 Col=1
10560 GOSUB Accept
10565 FOR Row=5 TO No_rows
10570 GOSUB Accept
10575 NEXT Row
10580 ELSE
10585 FOR Row=2 TO No_rows
10590 GOSUB Accept
10595 NEXT Row
10600 ELSE
10605 END IF
10610 ELSE
10615 Row=1
10620 Col=1
10625 GOSUB Accept
10630 END IF
10635 Col=1
10640 Old_col=1
10645 IF NOT Old_row THEN
10650 Row=1
10655 Old_row=1
10660 ELSE
10665 Row=Old_row
10670 END IF
10675 CALL Sc(0,0,Spacing*(Row-1)+1,(St1+2)*(Col-1)+1,Ptr$)
10680 RETURN
10685 !
10690 Knob_service:!
10695 Slowdown=10
10700 Kx=KNOBX+Kx
10705 Ky=KNODY+Ky
10710 IF ABS(Kx)<Slowdown AND ABS(Ky)<Slowdown THEN 10775
10715 IF No_cols=1 THEN Ky=Kx
10720 IF Kx>0 THEN Col=Col+1
10725 IF Kx<0 THEN Col=Col-1
10730 IF Ky>0 THEN Row=Row+1
10735 IF Ky<0 THEN Row=Row-1
10740 GOSUB Rc_Check
10745 CALL Sc(0,0,Spacing*(Old_row-1)+1,(St1+2)*(Old_col-1)+1,Clr$) !
Clear
10750 CALL Sc(0,0,Spacing*(Row-1)+1,(St1+2)*(Col-1)+1,Ptr$) !

```

```

Print Old_row=ROW
10755 Old_col=Col
10760 Kx=0
10765 RETURN !
10770

10780 Kbd_service:
10785 K$=KBDS
CALL Sc(0,0, Spacing*(Old_row-1)+1, (St1+2)*(Old_col-1)+1, Clear$)
10790 IF LEN(K$)<2 THEN 10935
10805 IF NUM(K$[1,1])>>255 THEN 10935
SELECT NUM(K$[1,2])
10810 CASE =60 ! LT arrow
COL=Col-1
10820 GOSUB Rc_check
10830 CASE =62 ! RT arrow
COL=Col+1
10835 GOSUB Rc_check
10840 CASE =71 ! Shift RT arrow
COL=No_cols
10850 CASE =72 ! No check, wrap disregarded
COL=1
10860 CASE =81 ! Shift LT arrow
10865 CASE =84 ! No check
10870 Row>No_rows
CASE =86 ! Shift DN arrow
10880 Row=Row+1
CASE =88 ! DN arrow
GOSUB Rc_check
10890 CASE =87 ! Shift UP arrow
Row=1
10895 CASE =94 ! No check
10900 Row=Row-1
GOSUB Rc_check
10910 END SELECT
10915 CALL Sc(0,0, Spacing*(Row-1)+1, (St1+2)*(Col-1)+1, Ptr$)
10920 Old_row=Row
10925 Old_col=Col
10930 RETURN !
10935

10940 Rc_check:
10945 SELECT Wrap
CASE =1 ! No wrap, hard limits
10950 IF Col=1 THEN Col=1
10955 IF Col>No_cols THEN Col=No_cols
10960 IF Row<1 THEN Row=1
10965 IF Row>No_rows THEN Row=No_rows
10970 IF Col>1 THEN Col=No_cols ! Wraparound on same row or col
10975 CASE =2
10980 IF Col=1 THEN Col=No_cols
10985 IF Col>No_cols THEN Col=1
10990 IF Row<1 THEN Row=No_rows
10995 IF Row>No_rows THEN Row=1 ! Wrap to next row or col; raster
11000 CASE =3
11005 IF Col<1 THEN
COL=No_cols
11010 Row=Row-1
11015 IF Row<1 THEN Row=No_rows ! Redundant test for completeness
11020 END IF
11025 IF Col>No_cols THEN
Col=1
11030 Row=Row+1
11040 IF Row>No_rows THEN Row=1 ! Redundant test for completeness
11045 END IF
11050 IF Row<1 THEN
Row=No_rows
11060 Col=Col-1
11070 IF Col>No_cols THEN Col=1
11075 END IF
11080 Row=Row-1
11085 IF Row>No_rows THEN Row=1 ! Redundant test for completeness
11090 IF Row<1 THEN
Row=No_rows
11095 Col=Col+1
11100 RETURN !
11105

11115 Check: ! Check for disallowed selections before Accept is
executed
11120 IF Menu_no>0 THEN ! Check for parameter change, do it
CALL New_default(Row)
GOSUB Scrn_Print
11125 ELSE !Redo the screen
CALL Check0(Row,Orow,Rrow)
11130 GOSUB Accept
11135 !Checks initial menu
11140 Row=Rrow !Accept new selection
11145 GOSUB Reject
11150 Row=Rrow !Row to reject
11155 GOSUB Reject
11160 Row=Rrow !Put the pointer back
11165 END IF
11170 RETURN
11175 Accept: ! !&Screens$(Row,Col)&"C"
B$="C&Screens$(Row,Col)*(Col-1)+3,B$) ! Inverse on
11180 CALL Sc(0,0, Spacing*(Row-1)+1, (St1+2)*(Col-1)+3,B$)
11185 CALL Sc(0,0, Men(Row,Col)=1
11190 Men(Row,Col)=1
11195 IF Array_Printed THEN GOSUB Array_Print
11200 RETURN !
11205 Reject: ! !&Screens$(Row,Col)
B$="C&Screens$(Row,Col)*(Row-1)+3,B$) ! Inverse off
11210 CALL Sc(0,0, Spacing*(Row-1)+1, (St1+2)*(Col-1)+3,B$)
11215 Men(Row,Col)=0
11220 IF Array_Printed THEN GOSUB Array_Print
11225 RETURN !
11230

11235 Set_wrap: ! ! No wrap with hard limits (1), normal wraparound (2), or raster
11240 INPUT "No wrap with hard limits (1), normal wraparound (2), or raster
(3)?"
11245 Wrap="C" Wrap
11250 Wrap=MIN(3,Wrap)
11255 Wrap=MAX(1,Wrap)
RETURN !

11260 Array_Print: ! ! No wrap with hard limits (1), normal wraparound (2), or raster
FOR R=1 TO No_rows
11270 FOR C=1 TO No_cols
11275 PRINT TABXY(59+2*C,R);Men(R,C)
NEXT C
11285 NEXT R
11290 Array_Printed=1
11295 RETURN
11300 Exit:KEY LABELS OFF
11305 SUBEND
11310 ! * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
11315 SUB Sc_Blank_Center_Row_Col.Strings$)
11320 IF Blank THEN OUTPUT KBD;CHR$(255&CHR$(75));
11325 IF NOT Center THEN 11335
11330 Col=40-INT(LEN(String$)/2+5)
11335 PRINT TABXY(Col+2*Row+2);String$;
11340 SUBEND
11345 ! * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
11350 New_Default: !
11355 SUB New_Default(Row)
11360 New_default !
11365 !Checks for parameter change, does it

```



```

12040 END IF
12045 !D$=DATE$(TIMEDATE) !For year, month, & day
12050 IF D$(1,1)="" THEN D$(1,1)="0"
12055 M=POS("No$") / D$(4,6,1)
12060 M=1+(M-1)/3
12065 T$=TIME$(TIMEDATE)
12070 OUTPUT N$ USING "#,2Z";M !Time
12075 T$=T$(1,2) !Just the hour
12080 Dtg$=D$(10,11)EMS&D$(1,2)&T$ !Time
12085 Dfile$=Prc$&Dtg$ !Turn on interrupt for EIP 578
12090 SUBEND !Set bit 2 on the EIP 578 SRQ byte
12095 Mount_id: !bit 2 = "counter searching"
12100 SUB Mount_id: !Bail out if needed
12105 Mount_id: !Bail out if needed
12110 OPTION BASE 1 !Turn on meas interrupt
12115 COM /Data/ Dfiles[20],File1$[16],Mount_id$[16]
12120 COM /Data/ Dfiles[20],File1$[16],Mount_id$[16]
12125 COM /Data/ Af(10,3),E(3000,2),F(500,2),Ne(100,2),Header(27)
12130 COM /Data/ Af(10,3),INTEGER TP(3000)
12135 CLEAR SCREEN !Wait for interrupt
12140 CONTROL 1,12,1 !Loop to wait
12145 PRINT TABXY(25,16),"BOLOMETER MOUNT IDENTIFICATION"
12150 PRINT TABXY(25,18),"Maximum length: 16 characters."
12155 INPUT "Enter the mount identifier:",Mount_id$ !Meas
12160 SUBEND !The following 4 subroutines set flags that are used by the Window
12165 !Turn off user soft key labels !subroutines to output the correct data displays; it was necessary
12170 Meas: !to accomplish that task using this code in order to avoid a problem
12175 SUB Meas !being updated.
12180 OPTION BASE 1 !CB=center window, "B" display
12185 COM /Data/ Dfiles[20],File1$[16],Mount_id$[16] !Count-Max count THEN End_meas
12190 COM /Data/ V(3000,2),E(3000,2),F(500,2),Ne(100,2),Header(27)
12195 COM /Data/ Af(10,3),INTEGER TP(3000)
12200 COM /Init_structs Tcv Rcv Sdr Volts(100) INTEGER Mode,Lss
12205 COM /Pwr_Set_in_ P_rf,R_0 !IF Window_c$="A" THEN
12210 COM /Io_Path_names @Eip_578,@ip_931,@dp_8200,@hp_3457 !New window$="CB"
12215 COM /Initial_value V_rf,0,V_rf,off !ELSE
12220 COM /Intr_Parameters Desired_freq,INTEGER No_of_intrs !New window$="CA"
12225 COM /Window_flags C$,Window_r$,Window_r$[,] !END IF
12230 COM /Screen_update Count,ftime,Freq,Pwr !RETURN
12235 COM /Stats_2_R,Prob,INTEGER Nruns !View r:
12240 !IF Window_r$="A" THEN !RB=right window, "B" display
12245 INTEGER Hpib !NEVER
12250 DIM New_window$[2] !CA=center window, "A" display
12255 Hpib=7 !RA=right window, "A" display
12260 !HP1B_interface select code
12265 ASSIGN @Eip_578 TO 719 !IP Power, mW
12270 ASSIGN @Eip_931 TO 720 !Mount resistance, Ohms
12275 ASSIGN @DP_8200 TO 714 !Measurement interval
12280 ASSIGN @HP_3457 TO 722 !Place to stop
12285 !Another place to stop
12290 P_rf=Header(12) !Counter for dc & freq
12295 R_0=Header(14) !Starting freq
12300 Desired_freq=0 !RF is off, initially.
12305 New_window$="XX" !Frequency set to DC
12310 Stop_frg=Header(7) !Initialize to "don't care" state
12315 Max_count=Header(9) !Center window, "A" display
N=1 !Right window, "A" display
12320 Freq=0 !(for interrupts from Window routines)
12325 Rf_on=0 !No. of points to use in stability test
12330 New_window$="A" !Determine system priority
12335 Stop_frg=Header(7) !Set local priority 1 higher for ON KEY
12340 Window_c$="A" !ON INTR Hpib,Lcl_prtv CALL Intr7 !Turn on interrupt for EIP 578
12345 Window_r$="A" !Set bit 2 on the EIP 578 SRQ byte
12350 Na=Lss !Read DVM (power meter)
12355 Sys_prt=VAL(SYSTEM$("SYSTEM_PRIORITY")) !Read clock & save
12360 Lcl_prt=Sys_prt+1 !Read DVM reading
12365 Lcl_prt=Sys_prt+1 !Save DVM reading
12370 V_rf_off=Read !When RF off, set V_rf_off for pwr calc
12375

!Measurement control block
!Time at beginning (date & start time)
!Note the time for elapsed time disp
!Start time for wait until cycle_time
!Set_interrupts:
!ON INTR Hpib,Lcl_prtv CALL Intr7 !Turn on interrupt for EIP 578
!Set bit 2 on the EIP 578 SRQ byte
!ENABLE INTR Hpib,2
!ON CYCLE Cycle_time,Lcl_prtv GOSUB E_meas !Turn on meas interrupt
!bit 2 = "counter searching"
12420 !ON KEY 0 LABEL "" Lcl_prtv GOSUB Man_freq_chg !Manual freq change
12430 !ON KEY 1 LABEL "",Lcl_prtv GOSUB View_C !Meas screen - change center section
12440 !ON KEY 5,Lcl_prtv GOSUB View_C !Meas screen - change right section
12450 !ON KEY 6,Lcl_prtv GOSUB View_r !Meas screen - change right section
12460 !ON KEY 9,Lcl_prtv CALL Blank !To blank CRT during measurement
12470 Wait:
12475 LOOP !Wait for interrupt
12480 GOSUB Time !Loop to wait
12485 IF Count-Max count THEN End_meas !IF Count-Max count THEN End_meas
12490 !IF Freq-Stop_frg THEN End_meas
12495 END LOOP !End Loop
12500 !
12505 !The following 4 subroutines set flags that are used by the Window
12510 !subroutines to output the correct data displays; it was necessary
12515 !to accomplish that task using this code in order to avoid a problem
12520 !created during interrupt service while the display screens were
12530 !
12535 View_c: !12535 View_c: !12535 View_c: !12535 View_c:
12540 IF Window_c$="A" THEN !IF Window_c$="A" THEN !IF Window_c$="A" THEN
12545 New_window$="CB" !New window$="CB" !New window$="CB"
12550 ELSE !ELSE !ELSE
12555 New_window$="CA" !New window$="CA" !New window$="CA"
12560 END IF !END IF !END IF
12565 RETURN !RETURN !RETURN
12570 View_r: !12570 View_r: !12570 View_r:
12575 IF Window_r$="A" THEN !IF Window_r$="A" THEN !IF Window_r$="A" THEN
12580 New_window$="RB" !New window$="RB" !New window$="RB"
12585 ELSE !ELSE !ELSE
12590 New_window$="RA" !New window$="RA" !New window$="RA"
12595 END IF !END IF !END IF
12600 RETURN !RETURN !RETURN
12605 !MAIN_MEASUREMENT_ROUTINE !MAIN_MEASUREMENT_ROUTINE !MAIN_MEASUREMENT_ROUTINE
12610 !Cycle_start=TIMEDATE !Cycle_start=TIMEDATE !Cycle_start=TIMEDATE
12615 !E_meas: !E_meas: !E_meas:
12620 Count=Count+1 !Count=Count+1 !Count=Count+1
12625 !MAIN !MAIN !MAIN
12630 !Measurement ROUTINE !Measurement ROUTINE !Measurement ROUTINE
12635 !Change Frequency ? !Change Frequency ? !Change Frequency ?
12640 !IF F(N,2)-119=Count THEN Next_frg=1 !Max time at any freq (60 min)
12645 !IF Next_frg THEN !Frequency change requested
12650 !CALL RF(0,Freq,11,RF_on) !First, turn off rf
12655 !END IF !END IF !END IF
12660 !Power Meter !Power Meter !Power Meter
12665 !Read DVM (power meter) !Read DVM (power meter)
12670 CALL Dvm(Sread) !Read clock & save
12680 V(Count,1)=TIMEDATE !Read DVM reading
12685 V(Count,2)=Sread !Save DVM reading
12690 CALL Dvm(Nread) !Read nanovoltmeter (thermopile)
12700 E(Count,1)=TIMEDATE !Read clock & save
12705 E(Count,2)=Nread !Save DVM reading
12710 IF NOT RF_on THEN !When RF off, set V_rf_off for pwr calc
12715 V_rf_off=Sread

```

```

END IF
IF RF_on THEN !When RF on, calc pwr & check pwr level
    CALL Power_lev_ohk(V_ref,Spread,Pwr)
END IF

! **** Temperature ****
OUTPUT 709;"CHAN 107" !Switch DVM to measure temperature
WAIT 1 !Read the temperature
CALL Dvm(Spread) !Convert to integer
Spread*1.E+5 !Trap too large spurious readings
IF Spread>3.2E-4 THEN !Set Max
    Spread=2.6E+4
    BEEP 2200,.01
END IF
TP(Count)=Spread !Save it in integer form
END IF

! **** Frequency ****
OUTPUT 709;"CHAN 101" !Switch DVM back to measure #2 Pwr Mtr
WAIT 1 !Switch freq change ? *****
NEXT.freq=1 !YES change frequency
IF Next.freq THEN !New frequency
    Freq=F(N,1)
    Desired.freq=F(N,1)
    F(N,2)=Count+1
    CALL Freq !Put starting count into freq array
    SELECT Freq !Check for dc bias on/off, rf on/off
    CASE =3 !Measurement finished
        GOTO End_meas !Finished
    CASE =-2 !Turn dc OFF
        CALL Dc(0,2) !Turn off #2 Type IV
    CASE =-1 !Turn dc ON
        CALL Dc(1,2) !Turn on #2 Type IV
    CASE =0 !Turn off rf
        CALL Rf(0,Freq,15,Rf_on) !Turn off rf
    CASE ELSE !Note the time
        Cftime=TIMEDATE
        CALL Power_lev_set(V_ref,Spread) !Save the initial value of V_ref
        V.ref=0.V.ref !Turn on rf at next freq
        CALL Rf(1,Freq,15,Rf_on) !Reset some stats variables
    END SELECT !Note the time
    N=N+1 !Increment counter
    Nruns=0 !Reset stat
    R=0 !Reset stat
    Prob=0 !Lower flag after freq change
    Next.freq=0
END IF
! **** Screen ****
CALL Screen_update !Write current values to the screen.
END IF

! **** Plot ****
PEN 1 !Do the plotting
PLOT E(Count,1)-Header(2),E(Count,2) !Lift pen between points - dotted line
PENUP !To reset a counter in Stats
IF Count=1 THEN Next.freq=1
IF Count=275 THEN
    CALL Stats(Na,E(Count,2),Next_freq)
    ! **** Check for Stability & Calculate Statistics
    CALL Stats(Na,E(Count,2),Next_freq)
END MAIN MEASUREMENT ROUTINE
-----
```

```

SELECT New_window$  

CASE "CA"  

CALL Window_c_a  

New_window$="XX"  

CASE "CB"  

CALL Window_c_b  

New_window$="XX"  

CASE "RA"  

CALL Window_r_a  

New_window$="XX"  

CASE "RB"  

CALL Window_r_b  

New_window$="XX"  

END SELECT  

RETURN  

!  

Man_freq.chg:  

13130 Next.freq=1  

13130 Man_freq.chg:  

13130 Next.freq=1  

13140 RETURN  

!  

13145 Bail_out:  

13155 Header(20)=0  

13160 CALL RF(0,Freq,15,1)  

13165 OUTPUT 722;"TRIG A"  

13170 !  

13175 End_meas:  

13180 Header(9)=Count  

13185 CALL New_size  

13190 !  

13195 OFF CYCLE  

13200 Stop_time=TIMEDATE  

13205 Header(10)=STOP_time  

13210 OUTPUT 722;"TRIG A"  

13215 GOSUB Dvm_Status  

13220 CALL RF(0,Freq,15,1)  

13225 VIEWPORT 0,128,0,100  

13230 WINDOW 0,128,0,100  

13235 !  

13240 IF Header(20) THEN  

13245 !  

13250 CSIZE 3,4  

13255 MOVE 115,3  

13260 LABEL "PROGRAM PAUSE"  

13265 PAUSE  

13270 STATUS 1,20;BL  

13275 IF BL=0 THEN CALL F  

13280 !  

13285 Exit:  

13290 GINIT  

13295 KEY_LABELS ON  

13300 SUBEND ! SUB Meas  

13305 ! * * * * *  

13310 Delay_start: !  

13315 SUB Delay_start  

13320 Sys_prtv=VAL(SYSTEN  

Lcl_prtv=Sys_prtv+  

13325 OUTPUT KBD;"K";  

13330 ENTER:KEY_LABELS OFF  

13340 PRINT TABXY(27,16)  

13345 TS=TIMES(TIMEDATE)  

13350 PRINT TABXY(27,18)  

13355 INPUT "Enter the d  

2:15

AM, etc)." Starts[$  

St$:Start[$1,2,&":  

PRINT TABXY(27,18)  

ON KEY 0 LABEL "S"  

ON KEY 1 LABEL "C"  

13375
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13380 FOR N=2 TO 8 !PRESS K0 TO TERMINATE" !To bail out
13381 ON KEY N LABEL " GOTO TOP
13390 NEXT N
13391 ON KEY 9 LABEL " BLANK CRT ",lcl_prtv CALL Blank !To blank CRT
13400 !
13405 KEY LABELS ON
13410 top:LOOP !Wait until time to start
13411 !Get the time
13412 Ts$=T$11,21&T$14,5 !Format to compare with Start$
13413 DISP " Present time: " ;St$,"
13414 IF Trs$>=Start$ THEN Exit
13415 END LOOP
13416 Exit:
13417 SUBEND
13418 ! * * * * * * * * * * * * * * * * * * * * * * * * * * * *
13419 Rf: ! !Turn rf on/off, & set frequency
13420 SUB RF_(On,Freq,Pwr,Rf_on) !Temporarily suspend ON CYCLE
13421 OFF CYCLE
13422 Rf_on KEY
13423 IF On THEN
13424 Rf_on: !To turn ON the RF
13425 DISABLE INTR 7 !To let everyone know
13426 BEEP 1500 , 01 !Set flag for status of RF signal
13427 Rf_on=1 !Connect power meter to leveler
13428 OUTPUT 709;"CLOSE 200" !1st set counter to correct band
13429 IF Freq<1 THEN
13430 OUTPUT 719;"B2" !Output 719;"B2"
13431 ELSE
13432 OUTPUT 719;"B3"
13433 END IF
13434 OUTPUT 720;"FR "&VAL$(Freq)&" GH,PO "&VAL$(Pwr)&" DB" !Set 931 f & p
13435 Rf_on=1 !Turn on the source
13436 WAIT 4 !Wait for source to settle
13437 !Meas 931 output freq
13438 Delta=Freq-Delt !Correction is desired minus actual
13439 Nfreq=Freq-Delt !Correction for source
13440 OUTPUT 720 USING "2A,X,2D,2D,X,2A";"FR",Nfreq,"GH" !Correct it
13441 WAIT 2
13442 OUTPUT 719;"PF "&VAL$(Freq)&" G" !Set EIP to lock at desired freq.
13443 WAIT 6 !Wait for mount to settle
13444 ENABLE INTR 7;2 !TO turn OFF the RF
13445 ELSE !Turn off rf source
13446 DISABLE INTR 7 !Disable EIP phase lock
13447 OUTPUT 719;"PFG" !Disconnect power meter from leveler
13448 WAIT 2 !Wait for mount to settle
13449 Rf_on=0 !Frequency is now zero
13450 Freq=0
13451 ENABLE INTR 7;2 !Back to wait for next interrupt
13452 END IF
13453 SUBEND ! * * * * * * * * * * * * * * * * * * * * * * *
13454 Rf_off: !Keep plot inside viewport
13455 !Rtime_graph: !Statistics to determine when to change
13456 SUB Rtime_graph !to next frequency
13457 OPTION BASE 1 !OPTION BASE 1
13458 COM /Data/ Drives[20],File$[16].Mount_Id$[16] !COM /Stats/ Avg(100,2),Ecal(100),INTEGER N
13459 COM /Data/ V(3000,2),E(3000,2),F(500,2),Ne(100,2),Header(27) !COM /Init_Stats/ Tcv,Rev,Env,Sdr,Volts(100),INTEGER Mode,Lss
13460 COM /Data/ Af(10,3),INTEGER Tp(3000), !Total # of measurements (array size)
13461 COM /XY_coordinates/ Timin,Timax,Vmin,Vmax !String for title
13462 NO=header(9) !Smaller letters
13463 ALLOCATE A$(60) !Labels ref. top center
13464 !MOVE A$(60) !Place to put ball out msg
13465 !CSIZE 2,6 !Place to put ball out msg
13466 LORG 6 !White
13467 MOVE 29,4 !Number of data points in the average & SD calculation
13468 PEN 1 !E - latest thermopile reading (recieve parameter)

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14055 ! Next_freq - flag indicating switch to next frequency (returned
14060 ! parameter) and flag to reset average counter
14065 ! Avg - In Col 1: freq; in Col 2: Avg thermopile V
14070 ! Ecal - scratch array for avg
14075 ! N - keep track of No. of measurement values added
14080 ! Ecal - scratch array for avg
14085 !REDIM Ecal(NA)
14090 ALLOCATE D(NA)
14095 IF Next_freq THEN
14100 N=0
14105 MAT Ecal= (0)
14110 Next_freq=0
14115 END IF
14120 CASE =NA
14125 N=NA+1
14130 SELECT N
14135 CASE <NA
14140 Ecal(N)=E
14145 GOTO Exit
14150 NEXT K
14155 Ecal(NA)=E
14160 CASE >NA
14165 FOR K=1 TO NA-1
14170 Ecal(K)=Ecal(K+1)
14175 NEXT K
14180 END SELECT
14185 Ecal(NA)=E
14190 MAT Volts= Ecal
14195 CALL Find_trend(Next_freq)
14200 IF Next_freq THEN
14205 N=0
14210 MAT Ecal= (0)
14215 END IF
14220 GOSUB Calc_sd
14225 CALL sd
14230 Calc_sd;
14235 Avg=SUM(Ecal)/NA
14240 MAT D= Ecal-Avg)
14245 MAT D= D - D
14250 SD=SQR(SUM(D)/(NA-1))
14255 IF SD<3.E-9 THEN BEEP 2200,.01
14260 RETURN
14265 Exit:
14270 SUBEND
14275 ! * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
14280 Dvnm: !
14285 SUB Dvnm(Nread)
14290 ENTER 712;Nread
14295 SUBEND
14300 ! * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
14305 !Turn Type IV (dc) on,off for power
14310 SUB Dvnm(Sread)
14315 ENTER 722;Sread
14320 SUBEND
14325 ! * * * * * * * * * * * * * * * * * * * * * * * * * * * *
14330 DC: !
14335 SUB Dc(On,Unit)
14340 DISABLE
14345 SELECT Unit
14350 CASE =1
14355 IF On THEN
14360 OUTPUT 709;"CLOSE 207"
14365 ELSE
14370 OUTPUT 709;"OPEN 207"
14375 END IF
14380 CASE =2
14385 ! Turn on #1 Type IV (110 VAC)
14390 !Turn off #2 Type IV (110 VAC)
14395 ELSE
14400 OUTPUT 709;"OPEN 209"
14405 END IF
14410 END SELECT
14415 ENABLE
14420 SUBEND
14425 ! * * * * * * * * * * * * * * * * * * * * * * * * * * *
14430 Std_dev: !
14440 SUB Std_dev
14445 OPTION BASE 1
14450 COM /Data/ Dfiles$[20],File$[16],Mount_id$[16]
14455 COM /Data/ V(3000,2),E(3000,2),F(500,2),Ne(100,2),Header(27)
14460 COM /Data/ Af(10,3),INTEGER N,Na,N1,N2
14465 INTEGER N,Na,N1,N2
14470 !Default
14475 N1=1
14480 N2=100
14485 ! Sys_prt=VAL(SYSTEM$("SYSTEM PRORITY"))
14490 !Determine system priority
14495 Lcl_prt=Sys_prt+1
14500 !Set local priority 1 higher for ON KEY
14505 SoftKey_interrupts:
14510 CONTROL 2,2,1
14515 CONTROL 1,12;0
14520 FOR N=0 TO 19
14525 ON KEY N LABEL " " GOTO TOP
14530 ON KEY 0 LABEL " PREV MENU "
14535 ON KEY 5 LABEL " CHANGE N1 "
14540 ON KEY 6 LABEL " CHANGE N2 "
14545 ON KEY 7 LABEL " CALCULATE SD "
14550 S_flg=1
14555 Top:LOOP
14560 IF S_flg THEN GOSUB Screen
14565 END LOOP
14570 !
14575 GOTO Exit
14580 !
14585 N_one:
14590 INPUT "Calculation starting point # ? ",NI
14595 S_flg=1
14600 RETURN
14605 !
14610 N_two:
14615 INPUT "Calculation stopping point # ? ",N2
14620 S_flg=2
14625 RETURN
14630 !
14635 Calc_sd:
14640 Na=N2-N1+1
14645 ALLOCATE Ecal(NA),D(NA)
14650 MAT Ecal= (0)
14655 MAT D= (0)
14660 FOR N=N1 TO N2
14665 Ecal(N+1-NA)=E(N,2)
14670 NEXT N
14675 AVG=SUM(Ecal)/NA
14680 MAT D= Ecal-(Avg)
14685 MAT D= D-D
14690 SD=SQR(SUM(D)/(NA-1))
14695 PRINT TABXY(20,14);CHR$(136);
14700 PRINT USING "6D.1D X,2A";Avg*1.E+9;"rv"
14705 PRINT TABXY(30,16);
14710 PRINT USING "4D.2D X,2A";SD*1.E+9;"nv"
14715 DEALLOCATE Ecal(*),D(*)
14720 RETURN
14725 Screen:

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T1=(N1,1)-Header(2))/60          !Starting elapsed time, min
T2=(E(N2,1)-Header(2))/60        !Stopping elapsed time, min
OUTPUT KBD:'K';
PRINT TABXY(5,2),CHR$(137)&"M I C R O - S D T"&CHR$(136)    !Clear screen
CLIP 0,80,62,100                !To draw a rectangle
PEN 1
14755
14760 FRAME
14765 PRINT CHR$(140)           !Cyan characters
14770 PRINT TABXY(18,6),"--"      !CALCULATE STANDARD DEVIATION -- --
14775 PRINT TABXY(10,8),"Starting point (N1) :" ;CHR$(136);N1;CHR$(140)
14780 PRINT TABXY(45,8),"Time:" ;CHR$(136);
14785 OUTPUT CRT USING "3Z,D,3A,3A";T1;CHR$((140));"min"
14790 PRINT TABXY(10,10),"Stopping Point (N2) :" ;CHR$(136);N2;CHR$(140)
14795 PRINT TABXY(45,10),"Time:" ;CHR$(136);
14800 OUTPUT CRT USING "3Z,D,3A,3A";T2;CHR$((140));"min"
14805 PRINT TABXY(10,12),"Total points:" ;CHR$(136);N2-N1+1;CHR$(140)
14810 PRINT TABXY(10,14),"Average:"
14815 PRINT TABXY(10,16),"Standard Deviation:"
14820 IF V(1,2)>OR E(1,2) THEN
14825 PRINT TABXY(59,17),CHR$(129)&" DATA IN MEMORY "&CHR$(128)
14830 IF Dfile$="" THEN
14835 PRINT TABXY(59,18),CHR$(129)&" (NO FILE NAME)"&CHR$(128)
14840 ELSE
14845 PRINT TABXY(59,18),CHR$(129)&" FILE:&Dfile$&CHR$(128)
14850 END IF
14855 ELSE
14860 PRINT TABXY(56,18),CHR$(129)&" NO DATA IN MEMORY "&CHR$(128)
14865 END IF
14870 S f19=0
14875 RETURN
14880 SUBEND
14885 Exit:
14890 ! * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
14895 Freq_change_pts: !
14900 SUB Freq_change_pts(Display)
14905 OPTION BASE 1
14910 COM /Data/ Dfiles[20],File1$[16],Mount_id$[16]
14915 COM /Data/ V(300,1),E(3000,2),F(500,2),Ne(100,2),Header(27)
14920 COM /Data/ Af(10,3),INTEGR(TP(3000)
14925 COM /Matrix_var/ Insert_matrix(50),Choice$[1]
14930 COM /Matrix_var/ INT32ER Lower_index,No_of_inserts
14935 !
14940 INTEGER N,N0,Start,Finish,X,Y,Z
14945 !
14950 IF NOT Display THEN
14955 GOSUB Update_screen
14960 IF Header(21) THEN
14965 CALL Random_f
14970 END IF
14975 SUBEXIT
14980 ELSE
14985 CLEAR SCREEN
14990 GOSUB Update_screen
14995 IF Header(21) THEN
15000 CALL Random_f
15005 GOSUB Update_screen
15010 END IF
15015 !
15020 update_values:
15025 Sys_Prt=VAL(SYSTEM$("SYSTEM PRIORITY"))
15030 Lcl_Prt=Sys_Prt+1
15035 !
15040 FOR Nr=0 TO 19
15045 ON KEY Nn LABEL "",Lcl_Prt GOSUB Wait_loop
15050 NEXT Nn
15055 ON KEY 5 LABEL " CHANGE FREQ ",Lcl_Prt GOSUB Change_freq
15060 ON KEY 6 LABEL " ADD FREQ S ",Lcl_Prt GOSUB Add_freqs
15065
15070 ON KEY 0 LABEL " CONTINUE ",Lcl_Prt GOTO Sub_exit
15075 GOSUB Update_screen
15080 IF Header(21) THEN
15090 CALL Random_f
15095 GOSUB Update_screen
15100 END IF
15105 KEY LABELS ON
15110 !
15115 Wait_loop:
15120 GOTO Wait_loop
15125 !
15130 Update_screen:
15135 N0l=Header(5)
15140 IF Header(19) THEN
15145 F(1,1)=-
15150 F(N0l+2,1)=0
15155 F(N0l+3,1)=-2
15160 F(N0l+4,1)=3
15165 Start=2
15170 Finish=N0l+1
15175 !
15180 F(N0l+1,1)=0
15185 F(N0l+2,1)=-3
15190 Start=1
15195 Finish=N0l
15205 END IF
15210 X=1
15215 Y=3
15220 PRINT TABXY(X,1),"No.",TABXY(X+5,1),"Freq (GHz)"
15225 FOR N=Start TO Finish
15230 IF F(N,1)<1 AND N<=No_elements THEN
15235 INPUT TABXY(X,1),"No.",TABXY(X+5,1),"Input freq. & starting points
15240 ELSE
15245 OUTPUT F$ USING "XX,Z,DDD";F(N,1)
15250 IF Start=1 THEN
15255 PRINT TABXY(X,1);N;TABXY(X+5,Y);F$
15260 ELSE
15265 PRINT TABXY(X,Y);N-1;TABXY(X+5,Y);F$
15270 END IF
15280 Y=Y-1
15285 SELECT Y
15290 CASE =19,=39,=59
15295 X=X+20
15300 Y=Z
15305 PRINT TABXY(X,1),"No.",TABXY(X+5,1),"Freq (GHz)"
15310 END SELECT
15315 NEXT N
15320 RETURN ! Update_screen
15325 !
15330 Add_freqs:
15335 Lcl_Prt_2=VAL(SYSTEM$("SYSTEM PRIORITY"))+2
15340 MAT Insert_matrix=(0)
15345 !
15350 FOR M=1 TO 7
15355 ON KEY M LABEL "",Lcl_Prt_2 GOSUB Wait_loop_2
15360 NEXT M
15365 ON KEY 5 LABEL "BEFORE FREQ #1" Lcl_Prt_2 GOSUB Insert_before
15370 ON KEY 6 LABEL "AFTER LAST FREQ" Lcl_Prt_2 GOSUB Insert_after
15375 ON KEY 7 LABEL "INSERT BETWEEN" Lcl_Prt_2 GOSUB Insert_between
15380 ON KEY 0 LABEL " CONTINUE ",Lcl_Prt_2 GOSUB Update_values
15385 !
15390 Wait_loop_2: ! Wait for ON KEY interrupt.
15395 GOTO Wait_loop_2
15400 !
15405 Insert_before:
15405

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```

15410 KEY LABELS OFF
15415 INPUT "No. of frequencies to be added: ", No_of_inserts
15420 FOR I=1 TO No_of_inserts
15425 INPUT "New frequency: ", Insert_matrix(I)
15430 NEXT I
15435 Choice$="B" ! Flag for "Before first frequency"
15440 CALL Insert_array
15445 GOSUB Update_screen
15450 KEY LABELS ON
15455 RETURN ! Insert_before
15460 !
15465 Insert_between: !
15470 KEY LABELS OFF
15475 INPUT "No. of frequencies to be added: ", No_of_inserts
15480 INPUT "No. of lower frequency (from display): ", Lower_index
15485 FOR I=1 TO No_of_inserts
15490 INPUT "New frequency: ", Insert_matrix(I)
15495 NEXT I
15500 Choice$="I" ! Flag for "In-between frequencies"
15505 CALL Insert_array
15510 GOSUB Update_screen
15515 KEY LABELS ON
15520 RETURN ! Insert_between
15525 !
15530 Insert_after: !
15535 KEY LABELS OFF
15540 INPUT "No. of frequencies to be added: ", No_of_inserts
15545 FOR I=1 TO No_of_inserts
15550 INPUT "New frequency: ", Insert_matrix(I)
15555 NEXT I
15560 Choice$="A" ! Flag for "After last frequency"
15565 CALL Insert_array
15570 GOSUB Update_screen
15575 KEY LABELS ON
15580 RETURN ! Insert_after
15585 !
15590 RETURN ! Add_freqs
15595 !
15600 Change_freq: !
15605 KEY LABELS OFF
15610 INPUT "No. of frequency to be changed: ", N_screen
15615 INPUT "Frequency (GHz)?: ", New_freq
15620 IF Header(19) THEN
15625 GOSUB Zero_flag_on
15630 ELSE
15635 GOSUB Zero_flag_off
15640 END IF
15645 KEY LABELS ON
15650 RETURN ! Change_freq
15655 !
15660 zero_flag_off: !
15665 F=N_screen
15670 IF F(N,1)=New_freq
15675 THEN
15680 OUTPUT F$ USING "XX,Z,DD";F(N,1)
15685 ELSE
15690 OUTPUT F$ USING "3D,DD";F(N,1)
15695 END IF
15700 SELECT N
15705 CASE <=16
15710 X=1
15715 Y=N+2
15720 CASE <=32
15725 X=21
15730 Y=N-14
15735 CASE <=48
15740 X=41
15745 Y=N-30

```

---

```

15750 END SELECT
15755 PRINT TABXY(X,Y);N;TABXY(X+5,Y);F$
15760 RETURN ! zero_flag_off
15765 !
15770 zero_flag_on: !
15775 N=N_screen+1
15780 F(N,1)=New_freq
15785 IF F(N,1)<1 THEN
15790 OUTPUT F$ USING "XX,Z,DD";F(N,1)
15795 ELSE
15800 OUTPUT F$ USING "3D,DD";F(N,1)
15805 END IF
15810 SELECT N_screen
15815 CASE <=16
15820 Y=N_screen+2
15825 CASE <=32
15830 X=21
15835 Y=N_screen-14
15840 CASE <=48
15845 X=41
15850 Y=N_screen-30
15855 END SELECT
15860 PRINT TABXY(X,Y);N;screen;TABXY(X+5,Y);F$
15870 RETURN ! zero_flag_on
15875 !
15880 Sub_exit: KEY LABELS OFF
15885 SUBND ! freq_change_Pts
15890 ! * * * * * * * * * * * * * * * * * * * * * * * * * * * *
15895 Runs: !
15900 SUB Runs(X(*),INTEGER N,Runs)
15905 ! This subroutine Runs determines the number of successive "runs"
15910 ! that occurs in the data array "X", and returns the result in "Nruns".
15915 !
15920 OPTION BASE 1
15925 INTEGER I,J
15930 Nruns=0
15935 I=1
15940 Segment_1: !
15945 IF (I-1)>N THEN GOTO Segment_2
15950 Oldiff=X(I+1)-X(I)
15955 FOR J=I+1 TO N-1
15960 Oldiff=PNSign(1.0,Oldiff)
15965 GOTO Segment_2
15970 END IF
15975 I=I+1
15980 GOTO Segment_1
15985 Segment_2: !
15990 FOR J=I+1 TO N-1
15995 Diff=X(J+1)-X(J)
16000 IF (Diff>0.) THEN
16005 Diff=PNSign(1.0,Diff)
16010 Oldiff=Diff
16025 END IF
16030 END IF
16035 NEXT J
16040 Nruns=Nruns+1
16045 SUBND ! Runs
16050 ! * * * * * * * * * * * * * * * * * * * * * * * * * * *
16055 Taub: !
16060 SUB Taub(X(*), INTEGER N, REAL Tau, Prob)
16065 ! This subroutine Taub computes the probability "Prob" from the data
16070 ! array contained in "X".
16075 !
16080 OPTION BASE 1
16085 INTEGER I,J

```

```

16090      REAL U,S,Susq,Tx,Tiechk,Xtmp,T,Vars
16091      !
16100      S=0.
16105      Susq=0.
16110      FOR I=1 TO N-1
16115      FOR J=I+1 TO N
16120      IF (U<>0.) THEN U=FNSign(1.,U)
16125      S=S-U
16130      Susq=Susq+U*U
16135      NEXT J
16140      NEXT I
16145      Tau=S/SQR(Susq*N*(N-1)/2)
16150      Tx=0.
16155      Tiechk=Susq-(N*(N-1))/2
16160      IF Tiechk<0. THEN
16170      MAT SORT X(*)
16175      Xtmp=X(1)
16180      T=1.
16185      FOR I=2 TO N
16190      IF X(I)=Xtmp THEN
16195      T=T+1.
16200      GOTO End_of_taubloop
16205      ELSE
16210      Xtmp=X(I)
16215      END IF
16220      IF T>1.0 THEN
16225      Tx=Tx+T*(T-1)*(2.*T+5.)
16230      T=1.0
16235      END IF
16240      End_of_taubloop:!
16245      NEXT I
16250      END IF
16255      Vars=(N*(N-1)*(2*N+5)-Tx)/18.0
16260      Z=SQR(Vars)
16265      CALL Erfc(Z,Prob)
16270      SUBEND ! Taub
16275      !
16280      FnSign: !
16285      DEF FNSign(A,B)
16290      ! This function "SIGN" returns:
16295      ! ABS(A) if B>0
16300      ! -ABS(A) if B<0
16305      !
16310      IF B<0 THEN
16315      RETURN -ABS(A)
16320      ELSE
16325      FNEND ! Sign
16330      END IF
16335      FnSign ! Sign
16340      !
16345      Erfc: !
16350      SUB Erfc(X,P)
16355      ! From FORTRAN code supplied by D. Vecchia, 870929.
16360      ! This subroutine computes the error function for the value X,
16365      ! and returns the answer in the variable P. The answer is not
16370      ! the standard result, but is computed on the basis of the last
16375      ! three conditional statements at the end of the subroutine.
16380      !
16385      DATA
0.319381530,-0.356563782,1.781477937,-1.8212515978,1.330274429,0.2316419
16390      READ B1,B2,B3,B4,B5,P
16395      Z=ABS(X)
16400      T=1./((1.+P*Z))
16405      CdF=(-(.39894228040143)*EXP(-.5*Z*Z))*
(B1*T+B2*T*B3*T*B4*T*T*B5*T*T*T*T)
16410      IF X<0 THEN P=1.-CdF

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16415      IF X=0 THEN P=.5
16420      IF X>0 THEN P=cdf
16425      SUBEND ! erf
16430      ! * * * * *
16435      Find_trend: !
16440      SUB Find_trend(Stable_run)
16445      ! The purpose of this subroutine is to determine if
16450      ! stability exist in a given set of data points. This
16455      ! is determined by computing two statistical values,
16460      ! denoted by R and Prob, and comparing these values to
16465      ! pre-determined constants. A decision is based on the
16470      ! results of this comparison as follows:
16475      ! R > Rcv or Prob > (1 - Tcv)
16480      ! If either of these conditions are met, then the sub-
16490      ! routine returns Stable_run=1, which means stability
16495      ! exist. If stability does not exist, then Stable_run=0.
16500      OPTION BASE 1
16505      COM /Init stats/ Tcv,Rcv,Env,Sdnr,Volts(100),INTEGER Mode,Lss
16510      COM /Stat5/2/ R,Prob,INTEGER Nruns
16515      REAL Vwork(100)
16520      INTEGER I,N
16525      !
16530      ! Compute the statistics of the number of runs, R:
16535      CALL RunS(Volts,*),Lss,Nruns
16540      R=(Nruns-Ehr)/Sdnr
16545      !
16550      ! Copy vector Volts into vector Work for use in SUB Taub;
16555      ! Taub computes the probability Prob:
16560      MAT Vwork=Volts
16565      CALL Taub(Vwork,*),Lss,Tau,Prob
16570      !
16575      ! - Nruns/R,Prob printed by Screen_update
16580      !
16585      ! Check for monotonically increasing/decreasing data.
16590      IF R>Rcv AND Prob-Tcv <(1-Tcv) THEN
16595      Stable_run=1
16600      ELSE
16605      !Data is not stable; fetch new data point and re-compute the
16610      !statistics.
16615      GOTO Sub_exit
16620      END IF
16625      Sub_exit: !
16630      SUBEND ! Find_trend
16635      ! * * * * *
16640      Settle1: !
16645      SUB Settle1(N1,N2,Erf,Nmid,Nst,Nsp,S_fg)
16650      !
16655      ! Frequency starting point
16660      ! N2: Frequency stopping point
16665      ! Nst: Beginning of settled run
16670      ! Erf: End of settled run
16675      ! Nmid: is the final settled value
16680      ! Nst: is the mid point of the array range from which Erf came
16685      ! S_fg: A flag to pause after every call to Find_trend subroutine
16690      !
16695      OPTION BASE 1
16700      INTEGER I,N
16705      COM /Data/ Dfile1$[20],Mount_ids[16]
16710      COM /Data/ V(3000,2),E(3000,2),F(500,2),Ne(100,2),Header(27)
16715      COM /Data/ Af(10,3),INTEGER tp(3000)
16720      COM /Init_stats/ Tcv,Rcv,Env,Sdnr,Volts(100),INTEGER Mode,Lss
16725      !
16730      Erf=0
16735      Nst=Np-Lss
16740      Nsp=Nt+Lss-1
16745      FOR N=Nst TO Nsp
16750      Erf=E(N,2)

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16755      NEXT N
16756      Erf_Erf / ( NSl-Nst+1 )
16757      Nmid=INT( (Nsl+NSp)/2 )
16758      !SUBEND
16759      !
16760      DP_8200: !
16761      !*****+
16762      SUB DP_8200( Value_0, Mode_0$ )
16763      !*****+
16764      !
16765      !Average
16766      !Mid_point
16767      !
16768      DP_8200: !
16769      !*****+
16770      SUB DP_8200( Value_0, Mode_0$ )
16771      !*****+
16772      !
16773      INPUT(S):
16774      Rev: 880503 BFR
16775      !
16776      INPUT(S):
16777      Value_0 - the numerical value of the desired
16778      voltage or current setting.
16779      Mode$_0 - a single character specifying the mode;
16780      "V" = voltage "A" = current.
16781      @DP_8200 - IO path name for HPIB address of the
16782      Data Precision source; addr: 713
16783      !
16784      V_ref_0 - initial value of the voltage setting when a
16785      new frequency is requested; the subroutine
16786      will not allow a setting lower than this
16787      value, and will re-set the DP 8200 to this
16788      value if Value_0 is less than V_ref_0.
16789      !
16790      OUTPUT(S):
16791      Output voltage or current setting on the DP 8200.
16792      !
16793      Maximum available output settings:
16794      Available Voltage
16795      100 mV range - 104.8575 mV
16796      10 V range - 10.8575 V
16797      100 V range - 104.8575 V
16798      Current
16799      100 mA range - 100 mA
16800      !
16801      Software lockouts (maximum output allowed):
16802      Max_voltage (or Min_voltage)
16803      Max_current (set at the line labelled "Software_lockout")
16804      !
16805      OPTION BASE 1
16806      COM /Io_Path_names/ @Ep_578,@Ep_931,@DP_8200,@Rp_3457
16807      COM /Initial_value/ V_rf_ref_0,V_rf_OFF
16808      !
16809      DIM Sign$[1],Ranges$[1]
16810      INTEGER No_dec_digits
16811      !
16812      Software_lockout:!
16813      Min_voltage=-1.6! 1.9 V originally
16814      Max_current=100 mA
16815      !
16816      IF Mode$="V" THEN
16817      IF Value<Min_voltage THEN
16818      Present_max=Min_voltage
16819      Unit$=" V"
16820      GOSUB Error_lockout
16821      BEEP 1500,.05
16822      Value_0=V_rf_ref_0
16823      Value=ABS(V_rf_ref_0)
16824      !
16825      END IF
16826      END IF ! Mode$="V"
16827      IF Mode$="A" THEN
16828      IF Value>Max_current THEN
16829      Present_max=Max_current
16830      !
16831      !Average
16832      !Mid_point
16833      !
16834      DP_8200: !
16835      !*****+
16836      SUB DP_8200( Value_0, Mode_0$ )
16837      !*****+
16838      !
16839      INPUT(S):
16840      Rev: 880503 BFR
16841      !
16842      INPUT(S):
16843      Value_0 - the numerical value of the desired
16844      voltage or current setting.
16845      Mode$_0 - a single character specifying the mode;
16846      "V" = voltage "A" = current.
16847      @DP_8200 - IO path name for HPIB address of the
16848      Data Precision source; addr: 713
16849      !
16850      V_ref_0 - initial value of the voltage setting when a
16851      new frequency is requested; the subroutine
16852      will not allow a setting lower than this
16853      value, and will re-set the DP 8200 to this
16854      value if Value_0 is less than V_ref_0.
16855      !
16856      OUTPUT(S):
16857      Output voltage or current setting on the DP 8200.
16858      !
16859      Maximum available output settings:
16860      Available Voltage
16861      100 mV range - 104.8575 mV
16862      10 V range - 10.8575 V
16863      100 V range - 104.8575 V
16864      Current
16865      100 mA range - 100 mA
16866      !
16867      Software lockouts (maximum output allowed):
16868      Max_voltage (or Min_voltage)
16869      Max_current (set at the line labelled "Software_lockout")
16870      !
16871      OPTION BASE 1
16872      COM /Io_Path_names/ @Ep_578,@Ep_931,@DP_8200,@Rp_3457
16873      COM /Initial_value/ V_rf_ref_0,V_rf_OFF
16874      !
16875      DIM Sign$[1],Ranges$[1]
16876      INTEGER No_dec_digits
16877      !
16878      Software_lockout:!
16879      Min_voltage=-1.6! 1.9 V originally
16880      Max_current=100 mA
16881      !
16882      IF Mode$="V" THEN
16883      IF Value<Min_voltage THEN
16884      Present_max=Min_voltage
16885      Unit$=" V"
16886      GOSUB Error_lockout
16887      BEEP 1500,.05
16888      Value_0=V_rf_ref_0
16889      Value=ABS(V_rf_ref_0)
16890      !
16891      END IF
16892      END IF ! Mode$="V"
16893      IF Mode$="A" THEN
16894      IF Value>Max_current THEN
16895      Present_max=Max_current
16896      !
16897      !Copy initial values into reference variables:
16898      Value=ABS(Value_0) ! Absolute value required.
16899      Mod$=UPC$(Mode_$) ! Force uppercase letters.
16900      !
16901      IF Mode$="V" THEN
16902      IF Value<Min_voltage THEN
16903      Present_max=Min_voltage
16904      Unit$=" V"
16905      GOSUB Error_lockout
16906      BEEP 1500,.05
16907      Value_0=V_rf_ref_0
16908      Value=ABS(V_rf_ref_0)
16909      !
16910      END IF
16911      END IF ! Mode$="V"
16912      IF Mode$="A" THEN
16913      IF Value>Max_current THEN
16914      Present_max=Max_current
16915      !
16916      !*****+
16917      SUB Power_lev_set(V_rf_ref,Sread)
16918      !*****+
16919      Power_lev_set:!
16920      !
16921      Power_lev_set(V_rf_ref,Sread)
16922      !
16923      INPUT(S) : Sread - power meter voltage, RF is off.
16924      OUTPUT(S) : V_rf_ref - reference voltage for the DP 8200.
16925      !

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17430 ! COM /Pwr_lev_set_in/ P_rf_R_0,V_rf_off
17440 ! COM /Initial_value/ V_ref_0,V_rf_off
17445 ! V_rf_off=Sread ! Power meter voltage, RF is off.
17450 ! V_rf_off=SR(V_rf_off*V_rf,-(P_rf_1000R_0))
17455 ! CALL Dp_8200(V_rf_ref,"V") ; Set the voltage reference to initial value.
17460 !
17465 ! SUBEND ! Power_lev_set
17470 !
17475 !
17480 ! Intr7:!
17495 !*****
17500 ! SUB Intr7
17505 ! COM /Io_path_names/ @Eip_578,@Eip_931,@Dp_8200,@Hp_3457
17510 ! COM /Intr_parameters/ Desired_freq,INTEGER No_of_intrs
17515 !
17520 ! No_of_intrs=No_of_intrs+1
17525 ! Source_freq=Desired_freq
17530 !
17535 ! OUTPUT @Eip_931 USING "2A,X,2D,2D,X,2A";"FR",Source_freq,"GH"
17540 ! WAIT 2
17545 !
17550 ! OUTPUT @Eip_578;"RS" ! Reset the counter to allow a measurement.
17555 ! WAIT 2 @Eip_578;Freq_m ! Measure the EIP uWave Source frequency with
17560 ! ENTER @Eip_578;Freq_m ! the EIP counter.
17565 !
17570 !
17575 ! Measured_freq=Freq_m/1.E+9 ! Convert to GHz.
17580 ! Offset=ROUND(Desired_freq-Measured_freq,5)! Units are GHz.
17585 ! IF Offset>2*Desired_freq THEN Offset=2*Desired_freq
17590 ! Source_freq=Source_freq+Offset
17595 ! OUTPUT @Eip_931 USING "2A,X,2D,2D,X,2A";"FR",Source_freq,"GH"
17600 !
17605 ! WAIT 2
17610 ! OUTPUT @Eip_578;"PF"&VAL$(Desired_freq)&"G"
17615 !
17620 !
17625 ! OUTPUT @Eip_931;"CLEARST"! Clear the status register of the 931
17630 ! source to prevent an interrupt from it.
17635 ! ENABLE INTR 7;2 ! Re-enable the interrupts (2=SRQ bit).
17640 ! OUTPUT @Eip_578;"SR02" ! SRQ on bit 2, "counter searching", enabled.
17645 !
17650 ! SUBEND ! SUB Intr7
17655 !
17660 ! Power_lev_chk:!
17665 !*****V_rf_on*****V_rf_off*****V_rf_on,Pwr
17670 ! SUB Power_lev_chk(V_rf_ref,V_rf_on,Pwr)
17675 !*****V_rf_off*****V_rf_on*****
17680 !
17685 ! INPUT(S) : V_rf - reference voltage for DP 8700.
17690 ! V_rf_on - power meter voltage, RF is on.
17695 ! OUTPUT(S) : V_rf - may be changed as determined by code.
17700 ! Pwr - calculated from last V_rf_off & V_rf_on
17705 !
17710 ! COM /Pwr_lev_set_in/ P_rf_R_0
17715 ! COM /Initial_value/ V_ref_0,V_rf_off
17720 ! Delta_v=DROUND(V_rf_ref-V_rf_on,5) !Difference: Ref-present reading
17725 ! SELECT Delta_v
17730 ! CASE <.001 !Leveler out of control - reset
17735 ! V_rf=ROUND(V_rf_on,5)+.0001!Compute new value
17740 ! CALL Dp_8200(V_rf_ref,"V") !Set 8200 to new value
17745 ! CASE >.05 !8200 has probably set itself to zero
17750 ! CALL Dp_8200(V_rf_ref_0,"V") !Reset 8200 to original value
17755 !
17760 ! END SELECT
17765 !

```

Pwr=1000\*(V\_rf\_off\*V\_rf\_off-V\_rf\_on\*V\_rf\_on)/R\_0 !Power calc

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```

18110 SUB Generate_freq(Nomore_f,INTEGER Row)
18115 *****
18120 !          Dest_matrix - A character variable that flags a need to insert
18125 !          data before the first frequency ("B"), in-between
18130 !          two frequencies ("I"), or after the last frequency
18135 !          ("A").
18140 !          Lower_index - the lower index number of Dest_matrix
18145 !          Upper_index - the upper index number of Dest_matrix
18150 !          (e.g., if Insert_array needed to be inserted between items
18155 !          3 and 4 of Dest_matrix, then Lower_index=3 and Upper_index=4)
18160 !          No_of_inserts - Total No. of elements in Dest_matrix (before
18165 !          Insert_array is inserted)
18170 !          No_of_inserts - No. of elements in Insert_array to be
18175 !          inserted
18180 !          into Dest_matrix
18185 !          (All variables are in COM /Matrix_var/)
18190 !          Elements in Insert_array are inserted in the proper place
18195 !          in the array Dest_matrix, and elements in Dest_matrix are
18200 !          moved up accordingly (no elements are deleted).
18205 !          Variable "No_elements" updated to the size of the new,
18210 !          expanded array.
18215 !          OPTION BASE 1
18220 !          COM /Data/ Dfiles[20],File1$[16],Mount_id$[16]
18225 !          ,Ne(100,2),Header(27)
18230 !          END IF
18235 !          Single set of frequencies
18240 !          IF Delta_freq<0 THEN
18245 !          No_of_freq=(Max_freq-Min_freq)/Delta_freq+1
18250 !          Header(5)=No_of_freqs
18255 !          Next_freq=Min_freq
18260 !          IF Header(19) THEN
18265 !          Start=2
18270 !          Finish=No_of_freqs+1
18275 !          IF Delta_freq>0 THEN
18280 !          Start=1
18285 !          Finish=No_of_freqs
18290 !          END IF
18300 !          REDIM F(Finish-2,2)
18305 !          FOR I=Start TO Finish
18310 !          F(I,1)=Next_freq
18315 !          Next_freq=Next_freq+Delta_freq
18320 !          NEXT I
18325 !          ELSE
18330 !          No_of_freq=7
18335 !          Header(5)=No_of_freq
18340 !          REDIM F(No_of_freq+2,2)
18345 !          FOR I=1 TO No_of_freq
18350 !          READ F(I,1)
18355 !          NEXT I
18360 !          DATA .1,.1,.5,.10,.15,.17,.18
18365 !          END IF
18370 !          END IF
18375 !          SUBEND ! Generate_freq
18380 !          *****
18385 !          Insert_array: !
18390 !          SUB Insert_array
18400 !          *****
18410 !          This subroutine inserts a subarray into a larger array. It is designed
18415 !          specifically for the program MIRCO_Cx?; and the large array is a two
18420 !          dimensional array with inserted items in the first column.
18425 !          INPUT(S): Dest_matrix - the array that receives the inserted items
18430 !          Insert_matrix - the array that is to be inserted into
18435 !          Dest_matrix
18440 !          Dest_matrix = Insert_matrix(1:No_of_inserts)
18445 !          Temp_matrix=A:B-Tot) = Temp_matrix
18450 !          CASE ="I": In-between frequencies
18455 !          IF Header(19) THEN
18460 !          A=Lower_index+2
18465 !          B=Lower_index+No_of_inserts+1
18470 !          Z=No_elements+1
18475 !          Tot=Total+1
18480 !          MAT Temp_matrixDest_matrix(A:Z)
18485 !          MAT Dest_matrix(A:B-Tot)= Temp_matrix
18490 !          END IF
18495 !          CASE ="B": Before first frequency
18500 !          IF Header(19) THEN
18505 !          A=1
18510 !          Z=No_elements
18515 !          Tot=Total
18520 !          END IF
18525 !          MAT Temp_matrixDest_matrix(A:Z)
18530 !          MAT Dest_matrix(A:B-1)= Insert_matrix(1:No_of_inserts)
18535 !          Temp_matrix=A:B-Tot) = Temp_matrix
18540 !          END IF
18545 !          CASE ="A": After last frequency
18550 !          IF Header(19) THEN
18555 !          A=No_of_inserts
18560 !          B=1
18565 !          Z=No_elements
18570 !          Tot=Total
18575 !          END IF
18580 !          MAT Temp_matrixDest_matrix(A:Z)
18585 !          MAT Dest_matrix(A:B)= Temp_matrix
18590 !          END IF
18595 !          ALLOCATE Temp_matrix(250),Dest_matrix(500)
18600 !          INTEGER A,B,Z
18605 !          Total=Header(5)+No_of_inserts! Total No. of elements for new array.
18610 !          MAT Dest_matrix=Header(5)
18615 !          No_elements=Header(5)
18620 !          END IF
18625 !          MAT Dest_matrix=(0)
18630 !          MAT Temp_matrix=(0)
18635 !          END IF
18640 !          IF Header(19) THEN
18645 !          MAT Dest_matrix(1:No_elements+1)= F(1:No_elements+1,1)
18650 !          ELSE
18655 !          MAT Dest_matrix(1:No_elements)= F(1:No_elements,1)
18660 !          END IF
18665 !          SELECT Choice$ !
18670 !          CASE ="B": Before first frequency
18675 !          IF Header(19) THEN
18680 !          A=2
18685 !          Z=No_elements
18690 !          Tot=Total+1
18695 !          ELSE
18700 !          A=1
18705 !          Z=No_elements
18710 !          Tot=Total
18715 !          END IF
18720 !          MAT Temp_matrixDest_matrix(A:Z)
18725 !          MAT Dest_matrix(A:B-1)= Insert_matrix(1:No_of_inserts)
18730 !          Temp_matrix=A:B-Tot) = Temp_matrix
18735 !          END IF
18740 !          CASE ="A": After last frequency
18745 !          IF Header(19) THEN
18750 !          A=No_of_inserts
18755 !          B=1
18760 !          Z=No_elements
18765 !          Tot=Total+1
18770 !          END IF
18775 !          MAT Temp_matrixDest_matrix(A:Z)
18780 !          MAT Dest_matrix(A:B)= Temp_matrix

```

```

18785 A=Lower_index+1
18790 B=Lower_index+No_of_inserts
18795 Z=No_of_elements
18800 Tot=Total
18805 END IF
18810 MAT Temp_matrix= Dest_matrix(A:Z)
18815 MAT Dest_matrix(A:B)= Insert_matrix(1:No_of_inserts)
18820 MAT Dest_matrix(B+1:Tot)= Temp_matrix
18825
18830 CASE "A"! After last frequency
18835 IF Header(19) THEN
18840 A=2
18845 Q=No_of_elements+2
18850 Tot=Total+1
18855 ELSE
18860 A=1
18865 Q=No_of_elements+1
18870 Tot=Total
18875 END IF
18880 MAT Dest_matrix(Q:Tot)= Insert_matrix(1:No_of_inserts)
18885 END SELECT
18890 ! MAT F(A:Tot,1)= Dest_matrix(A:Tot)
18895 Header(5)=Total ! Update variable for new matrix size.
18900 ! DEALLOCATE Temp_matrix(*),Dest_matrix(*)
18910 ! SUBEND! Insert_array
18920 ! SUBEND! Insert_array
18925 ! Window_left: ! Left window
18930 Window_left: ! Left window
18935 ! SUB Window_left
18940 ! *****
18945 ! *****
18950 !
18955 ! OPTION BASE 1
18960 !
18965 COM /Data/ Dfiles[20].File1$[16].Mount_id$[116]
18970 COM /Data/ V(3000,2),E(3000,2),F(500,2),Ne(100,2),Header(27)
18975 COM /Data/ Af(10,3),INTEGER TP(3000)
18980 !
18985 PRINT TABXY(7,3),"HEADER INFO"
18990 PRINT TABXY(1,4),"Mount ID: ";CHR$(136);";Mount_id$";CHR$(140)
18995 PRINT TABXY(1,5),"File name: ";CHR$(136);";DATE$ (TIMEDATE)
19000 PRINT TABXY(1,6),"Start Time: ";CHR$(136);";DATES (TIMEDATE)
19005 PRINT TABXY(14,7),"CHR$(136);";CHR$(136);";TIMES (TIMEDATE)
19010 PRINT TABXY(1,8),"Start Freq: ";CHR$(136);";Header (6);";GHz " ;CHR$(140)
19015 PRINT TABXY(1,9),"Stop Freq: ";CHR$(136);";Header (7);";GHz " ;CHR$(140)
19020 !
19025 SUBEND ! Window_left
19030 !
19035 Window_c.a: ! Center window
19040 ! *****
19045 SUB Window_c.a
19050 !
19055 ! OPTION BASE 1
19060 COM /Data/ Dfiles[20].File1$[16].Mount_id$[116]
19065 COM /Data/ V(3000,2),E(3000,2),F(500,2),Ne(100,2),Header(27)
19070 COM /Data/ Af(10,3),INTEGER TP(3000)
19075 COM /Data/ Window_c$,Window_r$,Window_r$a
19080 COM /Screen_update/ Count,Cftime,Freq,Pwr
19085 !
19090 ! Window_c$="A"
19095 FOR Row=3 TO 7
19100 PRINT TABXY(28,Row);
19110 NEXT Row
19115 !
19120 PRINT TABXY(34,3),CHR$(140);"LAST READING"
19125 PRINT TABXY(28,4),"Total time:"
19130 PRINT TABXY(28,5),"Elapsed time:"
19135 PRINT TABXY(28,6),"Total count:"
19140 PRINT TABXY(2,9),CHR$(136);;"Press K5 for next window";CHR$(128)
19145 CALL Screen_update
19150 !
19155 ! SUBEND ! Window_c.a
19160 !
19165 ! *****
19170 Window_r.a: ! Right window
19175 ! *****
19180 SUB Window_r.a
19185 ! *****
19190 !
19195 OPTION BASE 1
19200 COM /Data/ Dfiles[20].File1$[16].Mount_id$[116]
19205 COM /Data/ V(3000,2),E(3000,2),F(500,2),Ne(100,2),Header(27)
19210 COM /Data/ Af(10,3),INTEGER TP(3000)
19215 COM /Window_flags/ Window_c$,Window_r$a
19220 !
19225 Window_r$="A"
19230 FOR Row=3 TO 8
19235 PRINT TABXY(55,Row);
19240 NEXT Row
19245 !
19250 PRINT TABXY(56,3),CHR$(140);;"THERMOPILE OUTPUT & TEMP"
19255 PRINT TABXY(55,4),"Thermopile"
19260 PRINT TABXY(55,5),"T File Avg:"
19265 PRINT TABXY(55,6),"T Std Dev:"
19270 PRINT TABXY(55,7),"Room Temp"
19275 PRINT TABXY(55,8),"Batch Temp"
19280 PRINT TABXY(55,9),CHR$(136);;"Dress K6 for next window";CHR$(128)
19285 CALL Screen_update
19290 !
19295 ! SUBEND ! Window_r_a
19300 !
19305 !
19310 Window_c_b: !
19315 ! *****
19320 SUB Window_c.b
19325 ! *****
19330 !
19335 OPTION BASE 1
19340 COM /Data/ Dfiles[20].File1$[16].Mount_id$[116]
19345 COM /Data/ V(3000,2),E(3000,2),F(500,2),Ne(100,2),Header(27)
19350 COM /Data/ Af(10,3),INTEGER TP(3000)
19355 COM /Window_flags/ Window_c$,Window_r$a
19360 !
19365 Window_c$="B"
19370 FOR Row=3 TO 7
19375 PRINT TABXY(28,Row);
19380 !
19385 !
19390 PRINT TABXY(32,3),CHR$(140);;"SYSTEM PARAMETERS"
19395 PRINT TABXY(28,4),"Frequency"
19400 PRINT TABXY(28,5),"Power Meter V:"
19405 PRINT TABXY(28,6),"Ref V:"
19410 PRINT TABXY(28,7),"Power"
19415 PRINT TABXY(2,9),CHR$(136);;"Press K5 for next window";CHR$(128)
19420 PRINT CHR$(136)
19425 CALL Screen_update
19430 !
19435 SUBEND ! Window_c_b
19440 !
19445 Window_r.b: !
19450 ! *****
19455 SUB Window_r.b
19460 ! *****

```

```

1 ! OPTION BASE 1
19450 COM /Data/ Dfiles[20],File$[16],Mount_ids[16],Mount_ids[16]
19450 COM /Data/ V(3000,2),E(3000,2),F(500,2),Ne(100,2),Header(27)
19450 PRINT TABXY(64,3),"STATISTICS"
19450 PRINT TABXY(55,4),"NO. in average:"
19450 PRINT TABXY(55,5),"Runs"
19450 PRINT TABXY(55,6),"R"
19450 PRINT TABXY(55,7),"Prob"
19450 PRINT TABXY(55,9),CHR$(136);;"Press K6 for next window";CHR$(128)
19450 PRINT CHR$(136)
19450 CALL Screen_update
19500 !
19500 Window_r$="B"
19500 FOR Row=3 TO 8
19500 PRINT TABXY(55,Row);;"Flags which header info is displayed.
19500 !
19500 NEXT Row
19500 !
19500 PRINT TABXY(64,3),CHR$(140);;"STATISTICS"
19500 PRINT TABXY(55,4),"NO. in average:"
19500 PRINT TABXY(55,5),"Runs"
19500 PRINT TABXY(55,6),"R"
19500 PRINT TABXY(55,7),"Prob"
19500 PRINT TABXY(55,9),CHR$(136);;"Press K6 for next window";CHR$(128)
19500 PRINT CHR$(136)
19500 CALL Screen_update
19500 !
19500 SUBEND ! Window_r$=B
19500 !
19550 Meas_disp: !
19550 1*****1*****
19550 SUB Meas_disp
19550 1*****1*****
19550 !
19550 ! OPTION BASE 1
19550 COM /Data/ Dfiles[20],File$[16],Mount_ids[16]
19550 COM /Data/ V(3000,2),E(3000,2),F(500,2),Ne(100,2),Header(27)
19550 COM /Data/ At(10,3),INTEGER TP(3000)
19550 COM /Window_flags/ Window_c$,Window_r$[1]
19550 COM /Screen_update/ Count,Cftime,Freq,Pwr
19550 !
19550 KEY LABELS OFF
19550 OUTPUT KBD;"K"
19550 PRINT TABXY(1,1),CHR$(137)&"M I C R O C C X"&CHR$(136)
19550 PRINT TABXY(30,1),CHR$(136);;" M E A S U R E M E N T   I N
19550 P R O G R E S S";CHR$(128)
19550 !
19550 PEN 3
19550 CLIP 0,128,63,92
19550 FRAME 0,100*RATIO,0,100
19550 VIEWPORT 0,128,1,63
19550 PLOT 41,63
19550 PLOT 41,92
19550 PLOT 83,92
19550 PLOT 83,63
19550 CLIP 0,128,1,63
19550 PEN 2
19550 FRAME
19550 PRINT CHR$(140)
19550 !
19550 CALL Window_left
19550 CALL Window_c_a
19550 CALL Window_r_a
19550 !
19550 PRINT TABXY(28,8),CHR$(140);;"See to next reading:";CHR$(136)
19550 !
19550 CALL rtme_graph
19550 SUBEND ! Meas_disp
19550 !
19550 Screen_update: !
19550 1*****1*****
19550 SUB Screen_update
19550 1*****1*****
19550 !
19550 OPTION BASE 1
19550 !
19795 !

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19800 COM /Data/ Dfiles[20],File$[16],Mount_ids[16]
19800 COM /Data/ V(3000,2),E(3000,2),F(500,2),Ne(100,2),Header(27)
19810 COM /Data/ Af(10,3),INTEGER TP(3000)
19810 COM /Initial_value/ V.ref_0,V_rf.off
19820 COM /Init_stats/ Tcv,Rev,Env,Sahr,Volts(100),INTEGER Mode,Lss
19825 COM /Stats/ 2/R_Prob,INTEGER Nruns
19830 COM /Window_flags/ Window_c$,Window_r$[1]
19830 COM /Screen_update/ Count,Cftime,Freq,Pwr
19835 COM /Screen_update2/ Avg,Sd
19840 !
19845 IF Window_c$="A" THEN !LAST READING
19845 Total_time=(TIMEDEAD-Header(2))/60 !Total time elapsed.
19855 IF Count<1 THEN Total_time=0 !Special first time thru
19860 PRINT TABXY(41,4),CHR$(136);!Move cursor for total time.
19865 PRINT USING "#,4D,D,X,3A";Total_time,"min"
19870 E_time=(TIMEDEAD-Cft_time)/60 !Elapsed time since last freq change
19875 IF Count<1 THEN E_time=0 !Special first time thru
19880 PRINT TABXY(41,5);!Move cursor for Elapsed time
19885 PRINT TABXY(41,6);!Move cursor for Elapsed time
19890 PRINT TABXY(41,7);!Display the count
19895 PRINT TABXY(42,6),Count;!Display the count
19900 GOTO Sub_exit
19900 !
19905 END IF ! Window_c$="A"
19910 !
19915 IF Window_c$="B" THEN !SYSTEM PARAMETERS
19920 PRINT TABXY(41,4);!Move cursor for Freq
19925 PRINT TABXY(41,5);!Move cursor for power meter voltage
19930 PRINT TABXY(40,5);!Move cursor for power
19935 Cnt=Count
19940 IF Count=0 THEN Cnt=1
19940 PRINT USING "#,MZ,6D,X,1A";V(Cnt,.2),"V"
19945 PRINT TABXY(40,6);!Move cursor for reference voltage
19950 PRINT USING "#,MZ,6D,X,1A";Vref_0,"V"
19955 PRINT TABXY(40,7);!Move cursor for power
19960 PRINT USING "#,2D,4D,X,2A";Pwr,"mW"
19965 END IF ! Window_c$="B"
19970 !
19975 IF Window_r$="A" THEN !THERMOPILE OUTPUT & TEMPS
19980 PRINT TABXY(70,4);!Move cursor for thermopile voltage
19985 Cnt=Count
19990 IF Count=0 THEN Cnt=1 !Special first time thru
19995 PRINT USING "#,3D,3D,X,3A";E(1.1E+6,"UV"
20000 PRINT TABXY(70,5);!Move cursor for average
20005 PRINT USING "#,3D,4D,X,2A";Avg*1.E+6!"Uv"
20010 PRINT TABXY(69,6);!Move cursor for SD
20015 PRINT TABXY(66,7);!Move cursor for room temperature
20020 PRINT TABXY(66,7);!Move cursor for room temperature
20025 Cnt=Count
20030 IF Count=0 THEN Cnt=1 !Special first time thru
20035 PRINT USING "#,2D,2D,X,6A";Tp(Cnt,1.E-3,"deg C"
20040 PRINT TABXY(66,8);!Move cursor for bath temperature.
20045 PRINT TABXY(62,7);!Move cursor for Prob
20050 PRINT USING "#,2D,3D,X,5A";Header(.18,"deg C")
20055 END IF ! Window_r$="A"
20060 !
20065 IF Window_r$="B" THEN !STATISTICS
20070 PRINT TABXY(70,4),Lss !Print readings in average
20075 PRINT TABXY(61,5);!Move cursor for runs
20080 PRINT TABXY(61,6);!Move cursor for R
20085 PRINT TABXY(61,7);!Move cursor for R
20090 PRINT TABXY(62,7);!Move cursor for Prob
20095 PRINT TABXY(62,8);!Move cursor for Prob
20100 PRINT TABXY(62,9);!Move cursor for Prob
20105 PRINT TABXY(62,10);!Move cursor for Prob
20110 END IF ! Window_r$="B"
20115 Sub_exit: !
20120 SubEND ! Screen_update
20125 !
20130 Blank:SUB Blank !To blank or unblank crt
20135 COM /Blank/ INTEGER Off !To keep track of CRT

```

```

20140 IF OFF THEN
20145   SET DISPLAY MASK 15          !Turn all 4 planes on
20150   Off=0                      !Indicate CRT is ON
20155   ELSE
20160     SET DISPLAY MASK 0        !Turn all 4 planes off
20165     Off=1                      !Indicate CRT is OFF
20170   END IF
20175   SUBEND ! Blank
20180   !
20185   Pre_bias:SUB Pre_bias(Setup) !To bias the mount for a time
20190   before the run
20195   OPTION BASE 1
20200   COM /Data/ Dfiles[20] File1$[16],Mount_id$[16]          !Calculations
20205   COM /Data/ V3000,2,E(3000,2,F(500,2),N(100,2),Header(27)
20210   COM /Data/ Af(10,3),INTEGER Tp(3000)
20215   COM /Init_stats/ Tcv Rcv Err Sdrn,Volts(100),INTEGER Mode,Lss
20220   COM /Scts_2/ R_Prob,INTEGER Nruns
20225   COM /Screen_update2/ Avg,Sd
20230   COM /Prebias/ On_dur          !Keep track of previous setting
20235   !
20240   Sys_prtvVAL(SYSTEM$("SYSTEM_PRIORITY")) !Determine system priority
20245   Lcl_prtv.Sys_prtv+1           !Set local priority 1 higher for ON KEY
20250   CLEAR SCREEN
20255   KEY LABELS OFF
20260   !
20265   IF Setup THEN
20270     IF Header(19) THEN On_dur=1 !Default, zero flag ON
20275     IF NOT Header(19) THEN On_dur=0 !Default, zero flag OFF
20280   END IF
20285   Cycle_time=Header(11)        !Measurement interval
20290   Na=Us                         !No. of points to use in stability test
20295   !
20300   GOSUB Print
20305   !
20310   IF Setup THEN
20315     ON KEY 0 LABEL " Continue !For setup
20320     ON KEY 1 LABEL " Chng ON time ",Lcl_prtv GOSUB Change_on
20325     FOR N=2 TO 9
20330     ON KEY N LABEL " " GOTO Top1
20335     NEXT N
20340   ELSE
20345     ON KEY 0 LABEL " Start meas !For measurement
20350     ON KEY 1 LABEL " " GOTO Top2
20355     ON KEY N LABEL " BLANK CRT ",Lcl_prtv CALL Blank !To blank CRT
20360   END IF
20375   !
20380   KEY LABELS ON
20385   IF Setup THEN
20390     TOP1:LOOP !Wait for input
20395   END LOOP
20400   ELSE
20405     Start$:TIME$(TIMEDATE) !Start time now
20410     GOSUB Calc
20415     IF On_dur>0 THEN
20420       CALL Dc(1,2)           !If On_dur=0 skip this
20425       ON DELAY On_dur*3600,Lcl_prtv GOSUB Dc_off !Turn off bias after
20430       delay
20435     ELSE
20440       GOSUB Dc_off          !If NO bias be sure dc off
20445     END IF
20450     TOP2:LOOP T$:TIME$(TIMEDATE) !Get the time
20455     T$=T$[1,2]&T$[4,5]      !Format to compare with Stp$
20460     DISP "Pre-bias off: ";Stop1$," Present time: ";T$ !Reset measurement counter
20465     IF Stable THEN Exit1 !Finished
20470   END LOOP
20475   END IF
20480   Calc: Stop1$=TIME$(TIME$(Start$)+On_dur*3600) !Time to shut off bias
20495   Stop1$=Stop1$[1,5]&":00" !Eliminate seconds
20500   Stop1$=Stop1$[1,2]&Stop1$[4,5] !Convert
20505   RETURN
20510   !
20515   Change_on: !To change duration
20520   KEY LABELS OFF
20525   INPUT "New ON time in hours?",On_dur
20530   GOSUB Print
20535   KEY LABELS ON
20540   RETURN
20545   !
20550   DC_off: !Turn off the dc bias
20555   CALL Dc(0,2)
20560   ON CYCLE Cycle_time,Lcl_prtv GOSUB EO_meas !Turn on meas interrupt
20565   RETURN
20570   !
20575   EO_meas: !To determine EO
20580   CALL Dnmv(Nread) !Read nanovoltmeter (thermopile)
20585   Avg1=Avg !Save avg from previous meas
20590   CALL Stats(Na,Nread,Stable) !Check for stability of thermopile
20595   IF Stable THEN !Reset some stats variables
20600   Nruns=0
20605   R=0
20610   Prob=0
20615   IF ABS(Nread)<1.E-6 THEN !If less than 1 uV, the bias is off
20620     Header(15)=Avg1 !Put EO in Header (Avg=EO)
20625     IF NOT Header(19) THEN !No zero correction, then
20630     Stable=0
20635     CALL Dc(1,2) !turn bias back on & wait for stability
20640   END IF
20645   END IF
20650   RETURN
20655   !
20660   Print: !Print screen
20665   PRINT TABX(27,4)," MOUNT PRE-BIAS "
20670   PRINT TABX(27,4)," MOUNT PRE-BIAS "
20675   PRINT TABX(27,6)," DC Bias ON for: ";On_dur;" hrs. "
20680   RETURN
20685   !
20690   Bailout: !To do a partial software init
20695   IF Header(19) THEN CALL Dc(0,2) !Be sure bias is off if zero correction
20700   EXIT: !Disable any interrupts left on
20705   OFF_DELAY !Disable any interrupts left on
20710   OFF_CYCLE !Disable any interrupts left on
20715   Exit:
20720   SUBEND !Pre_bias
20725   !
20730   Re_set:SUB Re_set
20735   OPTION BASE 1
20740   COM /Data/ Dfiles[20],File1$[16],Mount_id$[16]
20745   COM /Data/ V(3000,2,E(3000,2),F(500,2),N(100,2),Header(27)
20750   COM /Data/ Af(10,3),INTEGER Tp(3000)
20755   COM /Init_stats/ Tcv,Rcv,Err,Sdrn,Volts(100),INTEGER Mode,Lss
20760   COM /Screen_update2/ Count,Crttime,Freq,Pwr
20770   COM /Stats_2/ R,Prob,INTEGER Nruns
20775   Dfile$="" !Clear data file name
20780   MAT V=(0) !Clear old data
20785   MAT E=(0)
20790   MAT F=(0)
20795   MAT Ne=(0)
20800   Count=0
20805   Header(9)=2400
20810

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20815      Lss=18          ! Stats init
20825      Rcv=-2.5        !No, in avg
20830      Tcv=.25         !Tuning constant
20835      Enr=(2.0*Lss-1.0)/3.0   !Tuning constant
20840      Sdhr=SQR((16.0*Lss-29.0)/90.0) !Expected No of runs
20845      Mode=1          !SD of No of runs
20850      R=0             !For stats
20855      Prob=0          !
20860      Nruns=0          !
20865      Avg=0            !Thermopile avg
20870      Sd=0             !Thermopile std dev
20875      Pwr=0            !
20880      SUBEND           !Re_set
20885      Random_f:SUB Random_f          !Sub to randomize freq list
20900      OPTION BASE 1
20905      COM /Data/ Dfiles[201].File$[16] Mount_id$[16]
20910      COM /Data/ V(3000,2),F(3000,2),F(500,2),Ne(100,2),Header(27)
20915      COM /Data/ Ar(10,3),INTEGER tp(3000)
20920      !
20925      INTEGER Nr,No1          !# of meas frequencies + final rf off
20930      No1=Header(5)
20935      !
20940      DIM Rm(50)          !Set up array for random nos
20945      DIM Rv(50)          !Set up vector array for sort
20950      !
20955      RANDOMIZE          !
20960      FOR Nr=1 TO 50      !Fill array with random nos
20965      Rm(Nr)=INT(1000*RND)
20970      NEXT Nr
20975      IF Header(19) THEN    !FOR account for zero correction
20980      REDIM Rm(No1+4)      !
20985      REDIM Rv(No1+4)      !
20990      Rm(1)=0              !To maintain original value
20995      Rm(No1+2)=1100
21000      Rm(No1+3)=1200
21005      Rm(No1+4)=1300
21010      MAT SORT Rm TO Rv
21015      MAT REORDER F BY Rv,1 !Sort order to vector
21020      ELSE
21025      REDIM Rm(No1+2)
21030      REDIM Rv(No1+2)
21035      Rm(No1+1)=1100
21040      Rm(No1+2)=1200
21045      Rm(No1+3)=1300
21050      MAT SORT Rm TO Rv
21055      MAT REORDER F BY Rv,1 !Reorder freq list by vector
21060      END IF
21065      !
21070      Sub_exit:           !
21075      SUBEND : Random_f

```

## APPENDIX E. Calibration Report

U.S. DEPARTMENT OF COMMERCE  
NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY  
ELECTRONICS AND ELECTRICAL ENGINEERING LABORATORY  
Boulder, Colorado

### REPORT OF CALIBRATION

#### COAXIAL THERMISTOR MOUNT NIST Model CN, Serial No. 05

Submitted by:

Customer's Name  
Customer's Address  
Customer's City, State and Zip

The measurements were performed under ambient environmental conditions of approximately 23°C and 40 percent relative humidity. The uncertainty of the calibration frequency is 1 ppm. The thermistor mount is operated at its designated resistance and is allowed to attain thermal equilibrium before beginning the test.

**Effective efficiency**  $\eta_e$  is defined as the ratio of the bolometrically substituted dc power in the thermistor mount to the net rf or microwave power delivered to the thermistor mount.

The effective efficiency of the thermistor mount was measured using the NIST automated coaxial microcalorimeter. Two connect-disconnect measurements were made in the microcalorimeter. On the first connect, measurements were made at five test frequencies. The frequencies are 0.1, 3, 10, 15 and 18 GHz. On the second connect the measurements at the five test frequencies were repeated. The results of the second series were compared with the first and found to agree to better than  $\pm 0.1$  percent. Then with the device still connected, the measurements were done at the full set of desired frequencies and these results are reported in Table 1. All the measurements were made at a power of 10 mW. Detailed descriptions of the calibration procedure, the system hardware, and the uncertainty evaluation process are found in references [1 - 3].

Test No. cn05\_84  
Date of Test: March 28, 1994  
Reference:  
Page 1 of 8

Coaxial Thermistor Mount  
Model CN, Serial No. 05

The uncertainties associated with the measurement of  $\eta_e$  are grouped in two categories according to the method used to estimate their numerical values [4]. The Type A evaluations of standard uncertainty are based on a statistical analysis of measurement results. The Type B evaluations of standard uncertainty are based on other methods. The standard uncertainties obtained by either the Type A or the Type B evaluations are expressed as a standard deviation.

The Type A evaluation of standard uncertainty in the measurement process is based on repeated measurements of another identical Model CN used as a check standard. The random effects are due to voltmeter resolutions, connector nonrepeatability, long term system variations, and system noise. This standard uncertainty is estimated to be 0.032 percent, independent of frequency. The estimate is subject to change in the future as additional measurements are made on the check standard.

The Type B evaluation accounts for uncertainties in the microcalorimeter correction factor and the associated measurement instrumentation. These estimates of standard uncertainty are based on measurement results and manufacturer's instrument specifications.

A combined standard uncertainty is calculated as the RSS (square root of the sum of the squares) combination of all the uncertainty components from both categories. The expanded uncertainty given in Table 1 is obtained by multiplying the combined standard uncertainty by a coverage factor of 2 and can be calculated using the equation,

$$U = 4.46 \times 10^{-4} f^2 + 5.34 \times 10^{-3} f + 0.180,$$

where U is the uncertainty in percent and f is the frequency in GHz.

For the Director,  
National Institute of  
Standards and Technology

Approved by:

Robert M. Judish, Group Leader  
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Test No. cn05\_84  
Date of Test: March 28, 1994  
Reference:  
Page 2 of 8

Coaxial Thermistor Mount  
Model CN, Serial No. 05

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- [1] Fred R. Clague, and Paul G. Voris, "Coaxial reference standard for microwave power," NIST Technical Note 1357, 1993. (U.S. Government Printing Office, Washington DC 20402-9325 or NTIS, Springfield, VA 22161).
- [2] Fred R. Clague, "Microcalorimeter for 7 mm coaxial transmission line," NIST Technical Note 1358, 1993. (U.S. Government Printing Office, Washington DC, 20402-9325 or NTIS, Springfield, VA 22161).
- [3] Fred R. Clague, "A calibration service for coaxial reference standards for microwave power," NIST Technical Note 1374, May 1995. (U. S. Government Printing Office, Washington DC 20402-9325 or NTIS, Springfield, VA 22161).
- [4] Barry N. Taylor and Chris E. Kuyatt, "Guidelines for evaluating and expressing the uncertainty of NIST measurement results," NIST Technical Note 1297, 1993. (U.S. Government Printing Office, Washington DC 20402-9325 or NTIS, Springfield, VA 22161).

Coaxial Thermistor Mount  
Model CN, Serial No. 05

Table 1.

Frequency (GHz)	Effective Efficiency	Type B Uncertainty (Percent)	Expanded Uncertainty (Percent)
0.05	0.9922	0.11	0.21
0.10	0.9951	0.13	0.23
0.15	0.9957	0.14	0.24
0.20	0.9959	0.16	0.26
0.25	0.9959	0.17	0.27
0.30	0.9959	0.18	0.28
0.35	0.9959	0.19	0.29
0.40	0.9958	0.20	0.30
0.45	0.9957	0.21	0.31
0.50	0.9956	0.22	0.32
0.55	0.9955	0.22	0.32
0.60	0.9953	0.23	0.33
0.65	0.9951	0.23	0.33
0.70	0.9949	0.24	0.34
0.75	0.9947	0.25	0.35
0.80	0.9942	0.25	0.35
0.85	0.9936	0.25	0.35
0.90	0.9926	0.25	0.35
0.95	0.9916	0.25	0.35
1.00	0.9905	0.25	0.35
1.05	0.9895	0.25	0.35
1.10	0.9889	0.25	0.35
1.15	0.9889	0.25	0.35
1.20	0.9892	0.25	0.35
1.25	0.9896	0.25	0.35
1.30	0.9900	0.25	0.35
1.35	0.9903	0.25	0.35
1.40	0.9906	0.25	0.35
1.45	0.9907	0.25	0.35
1.50	0.9907	0.25	0.35
1.55	0.9907	0.25	0.35
1.60	0.9906	0.25	0.35
1.65	0.9903	0.25	0.35
1.70	0.9901	0.25	0.35
1.75	0.9898	0.25	0.35
1.80	0.9894	0.25	0.35

Test No. cn05\_84  
Date of Test: March 28, 1994  
Reference:  
Page 4 of 8

Coaxial Thermistor Mount  
Model CN, Serial No. 05

Table 1. (con't)

Frequency (GHz)	Effective Efficiency	Type B Uncertainty (Percent)	Expanded Uncertainty (Percent)
1.85	0.9889	0.25	0.35
1.90	0.9884	0.25	0.35
1.95	0.9879	0.25	0.35
2.00	0.9873	0.25	0.35
2.10	0.9863	0.25	0.35
2.20	0.9855	0.25	0.35
2.30	0.9851	0.25	0.35
2.40	0.9849	0.25	0.35
2.50	0.9849	0.25	0.35
2.60	0.9851	0.25	0.35
2.70	0.9852	0.25	0.35
2.80	0.9854	0.25	0.35
2.90	0.9855	0.25	0.35
3.00	0.9856	0.25	0.35
3.10	0.9855	0.25	0.35
3.20	0.9855	0.25	0.35
3.30	0.9853	0.25	0.35
3.40	0.9851	0.25	0.35
3.50	0.9849	0.25	0.35
3.60	0.9847	0.25	0.35
3.70	0.9845	0.25	0.35
3.80	0.9843	0.25	0.35
3.90	0.9840	0.25	0.35
4.00	0.9837	0.25	0.35
4.20	0.9831	0.26	0.36
4.40	0.9826	0.26	0.36
4.60	0.9821	0.26	0.36
4.80	0.9816	0.26	0.36
5.00	0.9811	0.26	0.36
5.20	0.9807	0.26	0.36
5.40	0.9802	0.26	0.36
5.60	0.9798	0.26	0.36
5.80	0.9793	0.26	0.36
6.00	0.9789	0.26	0.36
6.20	0.9785	0.26	0.36
6.40	0.9780	0.26	0.36

Test No. cn05\_84  
Date of Test: March 28, 1994  
Reference:  
Page 5 of 8

Coaxial Thermistor Mount  
Model CN, Serial No. 05

Table 1. (con't)

Frequency (GHz)	Effective Efficiency	Type B Uncertainty (Percent)	Expanded Uncertainty (Percent)
6.60	0.9776	0.26	0.36
6.80	0.9771	0.26	0.36
7.00	0.9766	0.26	0.36
7.20	0.9760	0.26	0.36
7.40	0.9752	0.26	0.36
7.60	0.9743	0.26	0.36
7.80	0.9741	0.26	0.36
8.00	0.9741	0.26	0.36
8.20	0.9739	0.26	0.36
8.40	0.9735	0.26	0.36
8.60	0.9731	0.26	0.36
8.80	0.9727	0.26	0.36
9.00	0.9724	0.26	0.36
9.20	0.9721	0.26	0.36
9.40	0.9717	0.26	0.36
9.60	0.9713	0.26	0.36
9.80	0.9710	0.26	0.36
10.00	0.9705	0.27	0.36
10.20	0.9701	0.27	0.37
10.40	0.9697	0.27	0.37
10.60	0.9691	0.27	0.37
10.80	0.9687	0.27	0.37
11.00	0.9684	0.27	0.37
11.20	0.9681	0.27	0.37
11.40	0.9677	0.27	0.37
11.60	0.9674	0.27	0.37
11.80	0.9672	0.27	0.37
12.00	0.9670	0.27	0.37
12.20	0.9667	0.27	0.37
12.40	0.9663	0.27	0.37
12.50	0.9661	0.27	0.37
12.75	0.9654	0.27	0.37
13.00	0.9648	0.27	0.37
13.25	0.9642	0.27	0.37
13.50	0.9634	0.27	0.37
13.75	0.9624	0.27	0.37

Test No. cn05\_84  
Date of Test: March 28, 1994  
Reference:  
Page 6 of 8

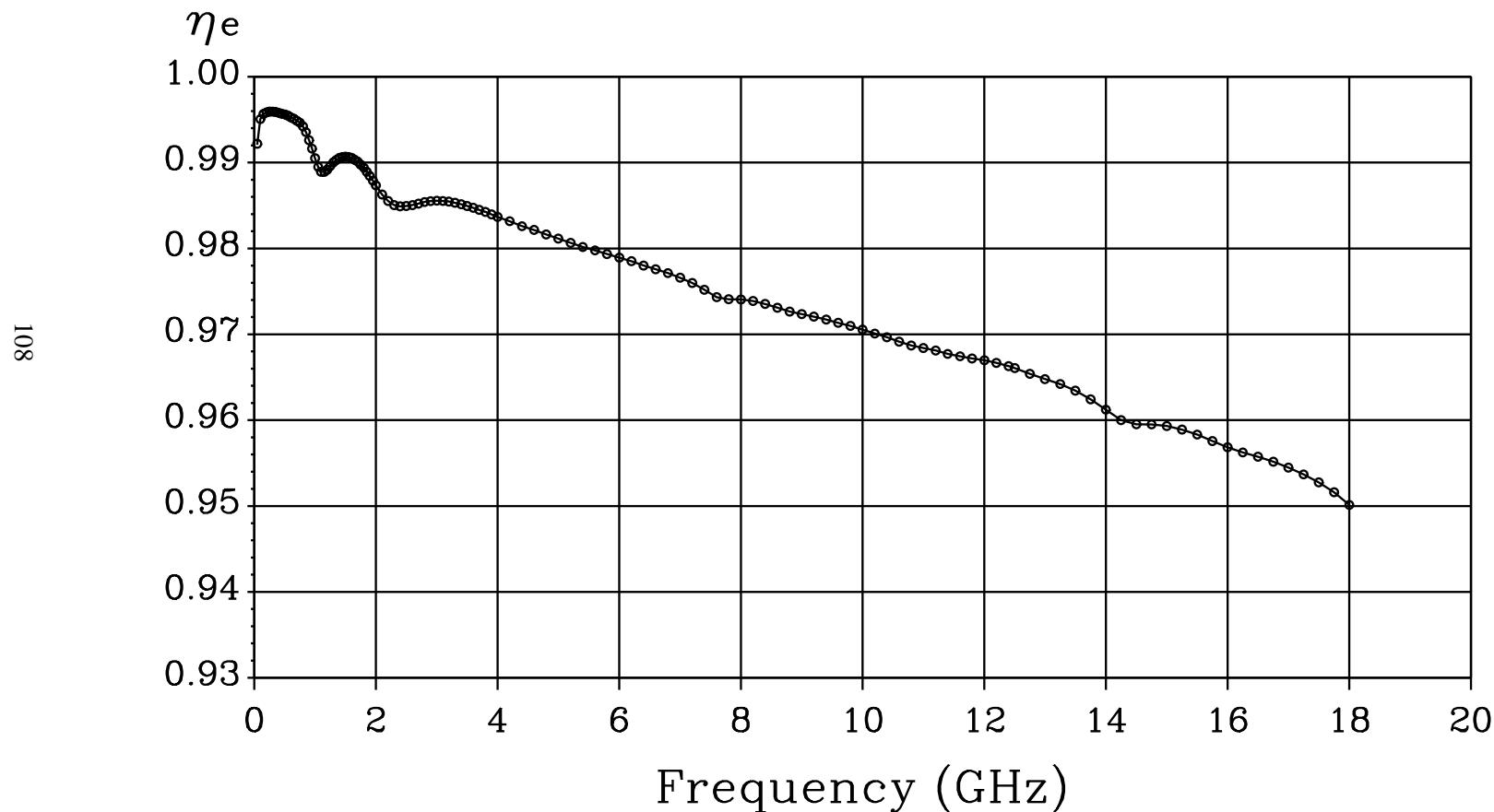
Coaxial Thermistor Mount  
Model CN, Serial No. 05

Table 1. (con't)

Frequency (GHz)	Effective Efficiency	Type B Uncertainty (Percent)	Expanded Uncertainty (Percent)
14.00	0.9612	0.27	0.37
14.25	0.9600	0.27	0.37
14.50	0.9595	0.27	0.37
14.75	0.9595	0.27	0.37
15.00	0.9593	0.27	0.37
15.25	0.9589	0.27	0.37
15.50	0.9583	0.27	0.37
15.75	0.9576	0.27	0.37
16.00	0.9568	0.28	0.38
16.25	0.9562	0.28	0.38
16.50	0.9557	0.28	0.38
16.75	0.9552	0.28	0.38
17.00	0.9545	0.28	0.38
17.25	0.9537	0.28	0.38
17.50	0.9527	0.28	0.38
17.75	0.9516	0.28	0.38
18.00	0.9501	0.28	0.38

Test No. cn05\_84  
Date of Test: March 28, 1994  
Reference:  
Page 7 of 8

## Coaxial Power Standard Microcalorimeter Measurements



Test No. cn05\_84

Date of Test: March 28, 1994

Reference:

Page 8 of 8

Rev. 003

## **APPENDIX F. Instrument Identification**

Table F1 identifies the commercial instruments used in the automated calibration system at the time this report was prepared. Items are listed as shown in figure 4.1. This identification does not imply recommendation or endorsement by NIST, nor does it imply that the identified items are necessarily the best available for the purpose.

Table F.1. Commercial instrument identification.

Item	Manufacturer	Model
1. Switch/Control Unit	Hewlett-Packard	3488A
2. Digital Voltmeter	Hewlett-Packard	3457A
3. Nanovoltmeter	Keithley	181
4. NBS Type IV Power Meter	-	-
5. DC Voltage Reference	Data Precision	8200
6. Microwave Locking Counter	EIP	578
7. Microwave Source	EIP	931
8. NBS Type II Power Leveler	-	-
9. Source and Meter Control Unit	-	-
Microwave Switch (See figure 4.2)	Hewlett Packard	P/N 33102A